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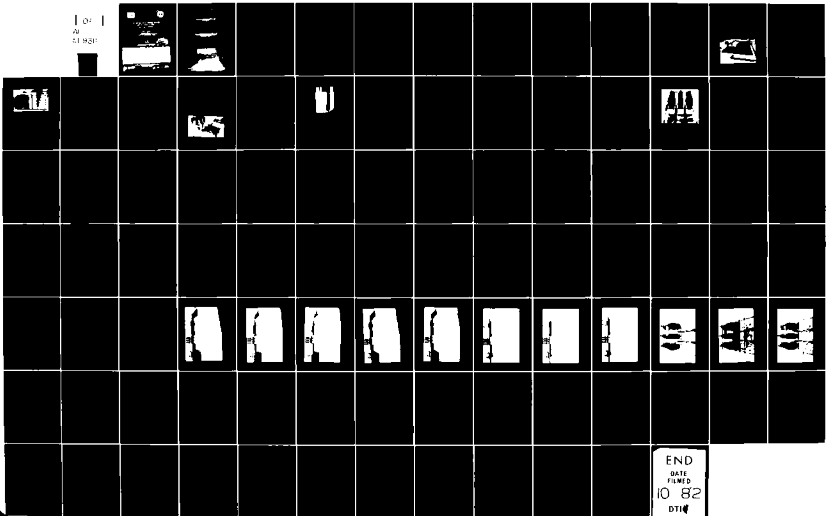

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A model study of the Blue Waters Ditch pumping station was conducted to develop a sump design which was free of adverse flow distribution, excessive circulation, and air-entraining vortices. Operation of the model with the original design sump resulted in severe vortices for many of the anticipated operating conditions because the opening in the divider wall allowed substantial crossflow between pump bays. Also, the relatively large distance between the pump bell and the backwall permitted substantial circulation of flow

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20. ABSTRACT (Continued).

in the original design sump. A continuous divider wall and a 0.5-ft spacing between the pump bell and the backwall resulted in substantial improvement of flow conditions at the pump intakes. However, the 90-deg change in flow direction that occurs just upstream of the sump resulted in an adverse distribution of flow approaching the pump intakes. Many modifications were tested to redistribute the approaching flow. Only converging sidewalls in conjunction with the continuous divider wall and the 0.5-ft spacing between the pump bell and the backwall were considered acceptable modifications to significantly improve flow conditions. Most modifications of the approach to the sump were ineffective because of the many possible combinations of flow direction that may enter the sump. Performance was investigated with velocities higher than the appropriately scaled Froudian velocities.

PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army, on 17 April 1978, at the request of the U. S. Army Engineer District, St. Louis. The studies were conducted by personnel of the Hydraulics Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), during the period April 1978 to January 1980 under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division. The tests were conducted by Messrs. S. T. Maynord and H. R. Smith under the supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch. This report was prepared by Mr. Maynord.

During the course of the model investigation, Mr. Joe Harz of the Lower Mississippi Valley Division and Messrs. Doug Hoy, Ron Dieckmann, Jim Cronin, Wayne Miller, Jr., Fred Bader, Jim Lamkins, and Jim Luther of the St. Louis District visited WES to observe model testing and discuss test results.

Commanders and Directors of WES during this testing program and the preparation and publication of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609347	kilometres
square feet	0.09290304	square metres
square miles (U. S. statute)	2.589998	square kilometres

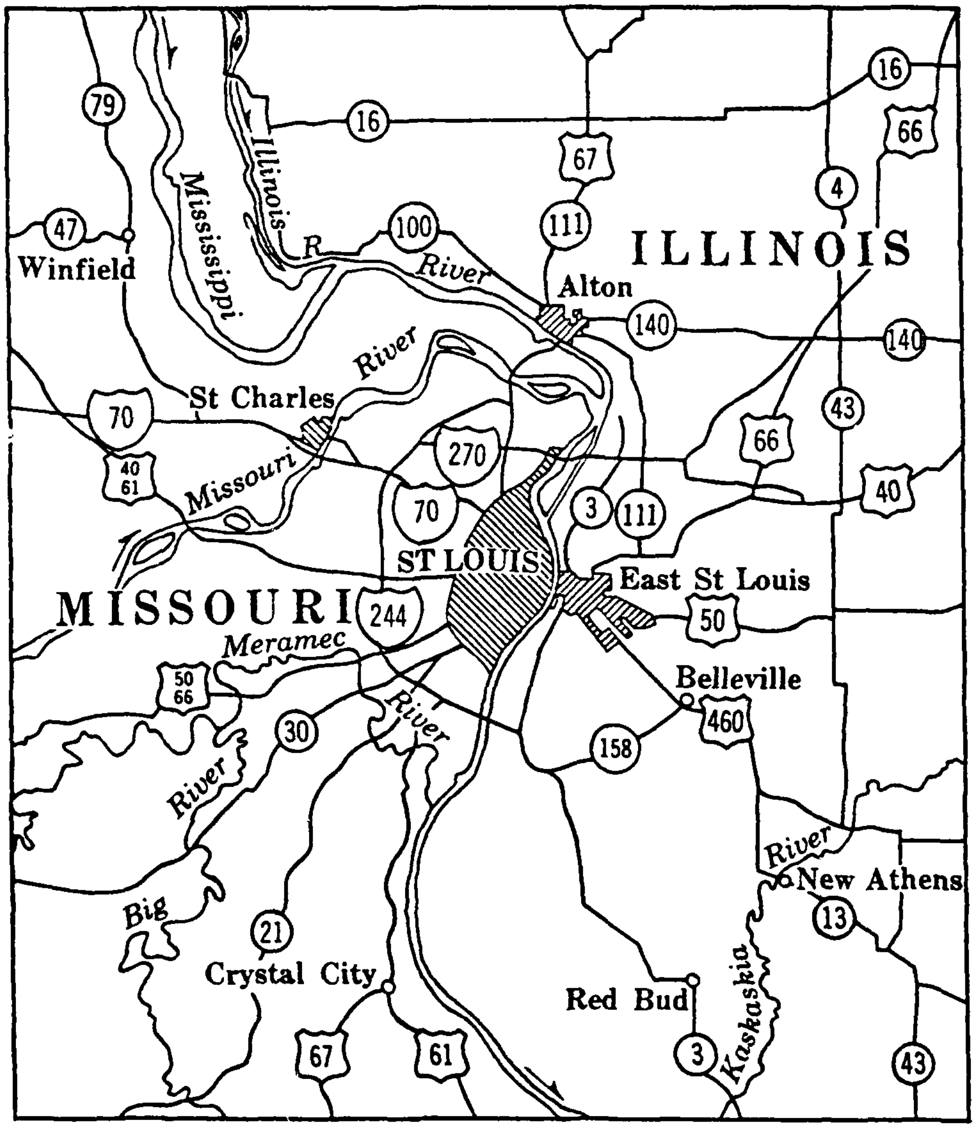

Figure 1. Vicinity map

BLUE WATERS DITCH PUMPING STATION
EAST ST. LOUIS, ILLINOIS
Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Blue Waters Ditch pumping station will be located on the left (east) bank of the Mississippi River across from the city of St. Louis, Mo. (Plate 1, Figure 1).

2. The drainage area of 13.1 square miles* consists entirely of Mississippi River floodplain which is highly urbanized and developed. The present ditch systems and pump installations are capable of handling only normal drainage requirements. During periods of above normal rainfall within the area, runoff accumulates in the bottoms so that existing ditches and adjacent banks are overtopped and water flows into surrounding areas. This flooding causes extensive damage and has plagued the area for years.

3. The plan of improvement for the Blue Waters Ditch area consists of a 600-cfs pumping station and approximately 4.4 miles of new and improved ditching. Runoff from the drainage area will flow to the pumping station via open channel. The proposed station will be of the wet-pit (sump) type and will employ three vertical shaft pumps to provide a total pumping capacity of 600 cfs. Trashracks will be provided to protect the pumps from debris. The pumps will discharge into a stilling basin on the opposite side of the levee. Minimum and maximum water-surface elevations under which the pumping station will operate are 396.0 and 403.8 ft NGVD,** respectively.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

** All elevations (el) cited herein are in feet referred to National Geodetic Vertical Datum (NGVD).

Purpose of Model Study

4. The model study was conducted to evaluate the hydraulic characteristics of the original design pumping station and to develop modifications, if needed, for improving flow conditions in the sump.

PART II: THE MODEL

Description

5. The model of the Blue Waters Ditch pumping station (Figure 2), constructed to a scale ratio of 1:13.5, included 200 ft of approach channel on each side of the pumping station, the sump, the trashracks, and the pump intakes. Flow through each model pump intake was provided by individual suction pumps that permitted simulation of various flow rates through one or more pump intakes.

6. Water used in the model was stored and recycled in a head box, and discharges were measured with turbine flowmeters. Water-surface elevations were measured with staff gages. Velocities were measured with an electromagnetic velocity probe. Current patterns were determined by observation of dye injected into the water and confetti sprinkled on the water surface. Pressure fluctuations directly beneath the pump

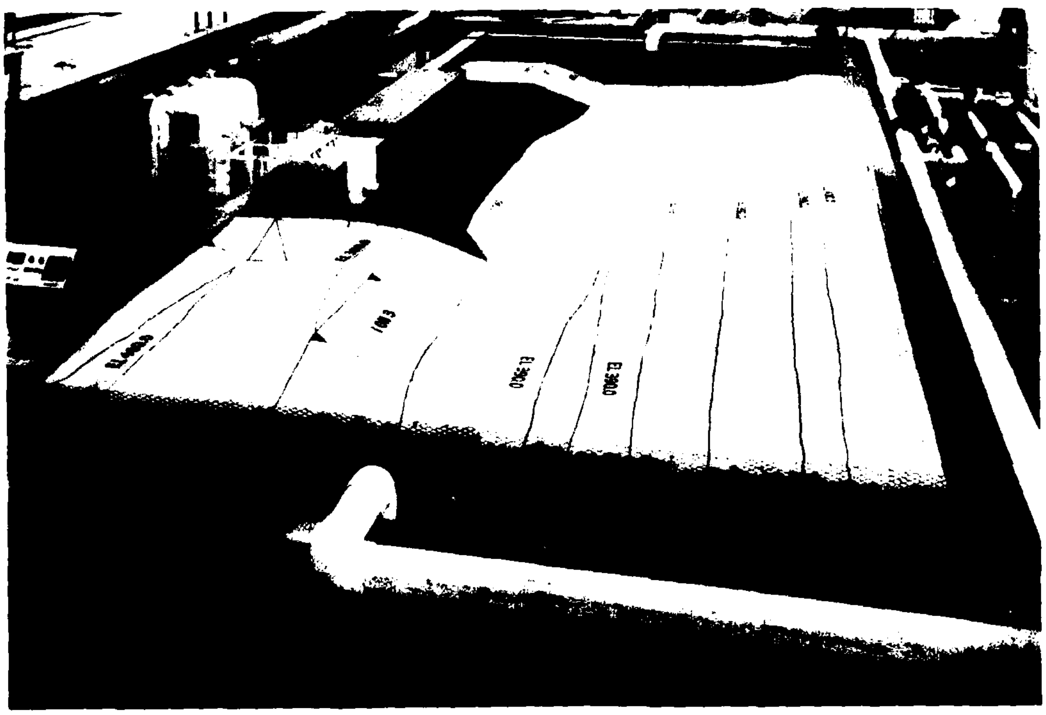

Figure 2. The 1:13.5-scale model

intakes were measured with 3-1/2-in.-diam (prototype) electronic pressure cells (Figure 3) mounted flush with the floor of the sump.

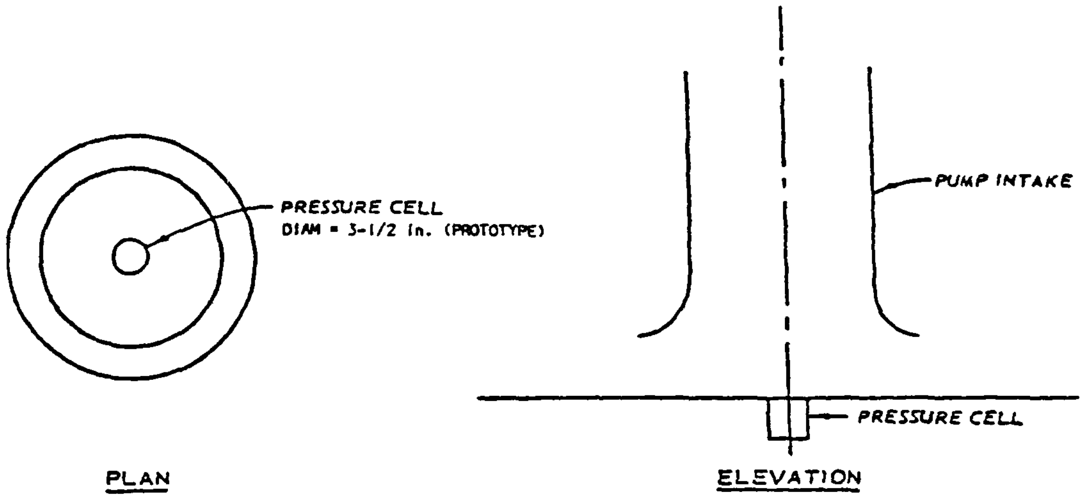

Figure 3. Pressure cell location

Rotational flow (swirl) in the pump intakes was measured with vortimeters (freewheeling propellers with zero-pitch blades) located inside each pump intake at the approximate location of the prototype pump impeller (Figure 4).

Scaling Relations

7. Evaluation of the proposed pumping station was achieved by using a physical model sufficiently large to have a relatively high Reynolds number of flow and scaled according to the Froudian criteria. The model is sized so that the Reynolds number defined as

$$R = \frac{Vd}{\gamma}$$

where

V = average velocity in pump suction column

d = diameter of pump suction column

γ = kinematic viscosity of fluid

Figure 4. Type 1 (original) pumping station sump and pump intakes

is greater than 10^5 to minimize scale effects due to viscous forces. Accepted equations of hydraulic similitude based on the Froudian criteria were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and prototype in terms of the model scale or length ratio L_r :

Characteristic	Dimension*	Model:Prototype Scale Relation
Length	L_r	1:13.5
Area	$A_r = L_r^2$	1:182.3
Velocity	$V_r = L_r^{1/2}$	1:3.67
Discharge	$Q_r = L_r^{5/2}$	1:669.6
Volume	$V_r = L_r^3$	1:2460.4
Weight	$W_r = L_r^3$	1:2460.4
Time	$T_r = L_r^{1/2}$	1:3.67

* Dimensions are in terms of length.

Model quantities were transferred to the prototype using these scale relations.

8. In addition, the St. Louis District asked that the U. S. Army Engineer Waterways Experiment Station (WES) evaluate the performance of the recommended sump design with velocities higher than the appropriately scaled Froudian velocities. Numerous investigators (Fraser and Harrison (1953), Iversen (1953), Denny (1956), Denny and Young (1957), Hattersley (1960), Zajdik (1977), Dicmas (1978), Dexter and Zeigler (1978), Chang (1979), and Chang and Larsen (1980)) have used velocities greater than Froudian velocities to achieve better similarity with respect to vortex formation. However increased velocities in the model may introduce nonsimilarities between model and prototype in the form of (a) increased surface disturbance which can inhibit vortex formation and (b) a distorted flow distribution that results from violating the proper ratio of inertial to gravitational forces (Froude number) in the model. Either of these can invalidate the results of testing with increased velocities.

9. Other investigators have found a limiting Reynolds number or other factors at which Froudian models must be operated to achieve similarity with respect to vortex formation. Daggett and Keulegan (1974) conducted vortex similarity tests using drain vortices in cylindrical tanks and defined a limiting Reynolds number

$$R = \frac{Q}{A\gamma}$$

where

Q = discharge

A = orifice radius

γ = kinematic viscosity

which must be greater than $5(10)^4$ to yield viscous effects negligible. The Reynolds number as defined by Daggett and Keulegan (1974) for the Blue Waters Ditch model is $1.6(10)^5$, thus indicating minimal viscous effects in the model. Jain, Raju, and Garde (1978) found that the conditions at which viscous forces become negligible in vertical downward pipe intakes is dependent on both Reynolds and Froude numbers. The Jain, Raju, and Garde (1978) criteria indicate that viscous scale effects in the Blue Waters Ditch model should be negligible. The work of Anwar and Amphlett (1980) with inverted pipe intakes shows that surface tension and viscosity effects become negligible when the radial Reynolds number

$$Rr = \frac{Q}{\gamma h}$$

where h equals submergence above bottom of intake pipe, is greater than $3(10)^4$. The results of Anwar and Amphlett (1980) show the Blue Waters Ditch model [$Rr = 2.2(10)^4 - 4.3(10)^4$] to be free of viscous and surface tension effects at all elevations except the highest sump elevation. Hecker (1981) reviewed available model-prototype comparisons of free surface vortices and found 16 projects where model flows were run at equal Froude numbers in model and prototype. Fourteen of these projects had model and prototype vortices essentially equal and five of the projects had vortices weaker in the model than in the prototype. Three projects were evaluated in which the Froude number in the model was 2 to 4.5 times the Froude number in the prototype. Two of these projects had essentially equal vortices in the model and prototype, while one of the projects had stronger vortices in the model than in the prototype. Hecker concludes from the model-prototype comparisons that designs that were developed from Froude-scale model tests to be vortex-free were indeed vortex-free in the prototype, and those having weak vortices in the model had weak vortices in the prototype. No cases were found where a weak model vortex corresponded to a strong prototype vortex resulting in operating problems.

PART III: TESTS AND RESULTS

Original Design

10. The 1:13.5-scale model of the original design is shown in Figures 2, 4, and 5 and Plate 2. The pumps are numbered as shown in Figure 5. Each of the three 54-in.-diam pumps has a discharge capacity ranging from 200 cfs at sump el 396.0 to 225 cfs at sump el 399.5 and 403.8. Pump bell details are shown in Plate 3. Performance of the sump was evaluated by visual observation of flow conditions and measurements of velocities, pressures on the floor of the sump directly below the vertical axis of the pump columns, and rotation of flow at the approximate position of the impeller in the prototype.

11. Inflow to the station can come from either direction and in various combinations from the two directions (see Figure 2). During the model study, inflow directions of 100 (percent) left (looking downstream), 100 right, and 50 left-50 right were tested to evaluate the sump design. Various flow conditions in the approach to the sump are illustrated in Photos 1-8. The eddies in the approach to the sump

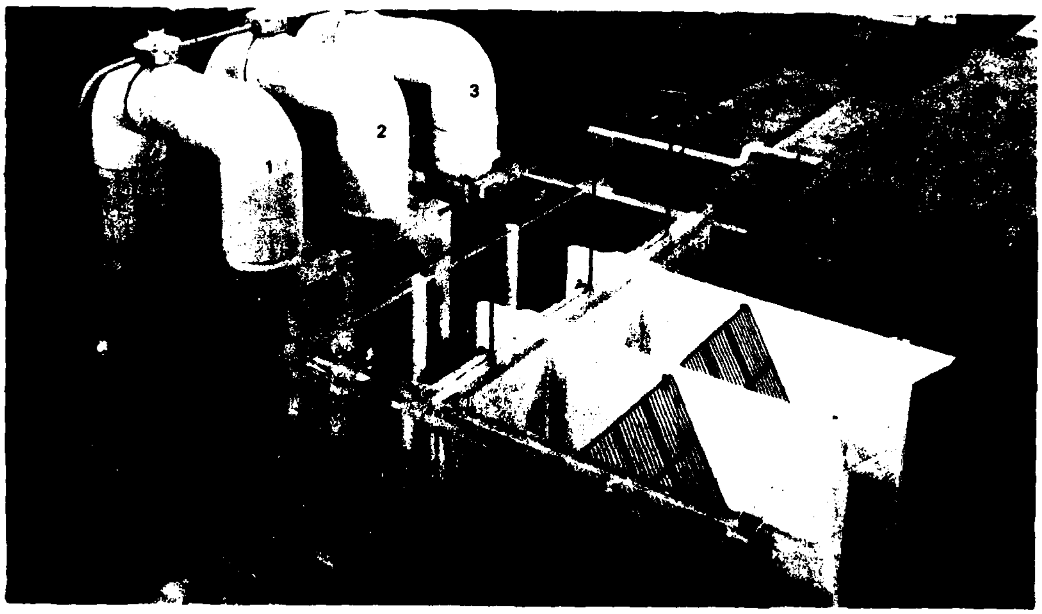

Figure 5. Type 1 (original) pumping station

resulted in uneven flow distribution entering the sump bays. These eddies were caused by the 90-deg change in flow direction that occurred just upstream of the sump. Even though velocities were low, the flow was severely contracted by the 90-deg change in direction and relatively short approach. Note the relatively less severe eddy action at sump el 403.8 (Photos 6-8).

12. Various flow conditions within the sump are shown in Photos 9-11. With all three pumps operating (Photo 9), the flow approaching the pumps was relatively uniformly distributed. With one or two pumps operating (Photos 10 and 11), the crossflow through the open divider wall caused an uneven distribution of flow approaching the pumps. Also, this open divider wall at the backwall caused the flow to approach the pumps from the side and rear. These factors resulted in air-entraining vortices (Figure 6) during many of the flow conditions with the original design. Figure 7 shows the stages in the development of an air-entraining vortex from a small depression in the water surface to a continuous air core extending into the pump intake. Prototype values of pressure fluctuations on the sump floor (expressed in feet of water) and rotational flow tendencies (expressed as the speed of revolution of the fixed-vane vortimeter and the rotational flow indicator, R_i*) are given

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* Rotational flow indicator is the ratio, R_i , of the blade speed, U , at the tip of the vortimeter blade to the average velocity, V_a , for the cross section of the suction column. The rotational flow indicator is computed according to

$$R_i = \frac{U}{V_a}$$

where

$U = \pi nd$

n = revolutions per second of the vortimeter

d = suction column diameter (used for blade length), ft

V_a = average suction column axial velocity = Q/A

Q = pump discharge, cfs

A = cross-sectional area of suction column, ft^2

The rotational flow indicator is a dimensionless method of expressing the speed of revolution of the vortimeter and has the advantage of having the same value in model and prototype. The rotational flow indicator is a relative measure of the approach flow symmetry and is equal to the tangent of the swirl angle as used by some investigators.

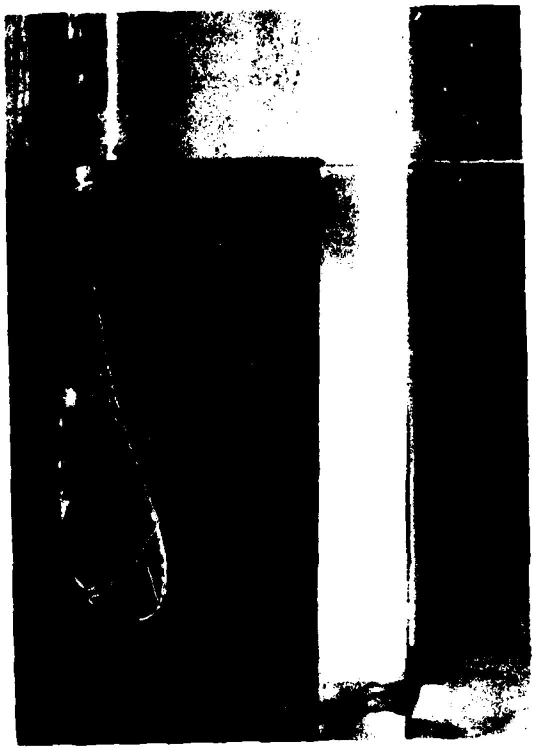


Figure 6. Air-entraining vortex developed in type 1 (original) design sump

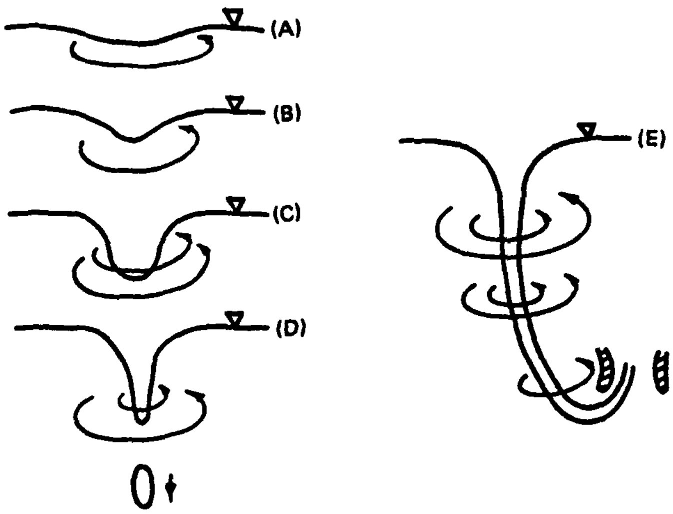


Figure 7. Stages in development of air-entraining vortex

in Table 1. Many times the vortimeter would rotate first in one direction and then the opposite direction. Vortimeter readings shown in the tables reflect the net rotation of the vortimeter over 1 min (model time) of observation.

13. Also shown in Table 1 are the most severe surface vortex types observed in the original design. The locations of the most severe vortices in the original design were at 4:00 to 5:00 o'clock and/or 7:00 to 8:00 o'clock with 12:00 o'clock being upstream along the center line of the pump bay. Velocities measured in the approach and within the sump are shown in Plates 4-6.

Alternate Designs

14. Many modifications to the original design were investigated to develop one that would uniformly distribute flow to the pump intakes. The first series of tests was directed at modifying the sump. Original and alternate designs are shown in Plates 7 and 8. Some of the modifications tested are not shown because they involved only minor changes to designs shown and were ineffective. Initially, only a few of the 63 tests listed in Table 1 were run for each alternate design. Many times, the problems associated with a given alternative were apparent from these tests; consequently running the remainder of the 63 tests would have been wasted effort. Other times, a given alternative would appear promising and additional tests were run for further evaluation.

15. In the type 2 design sump (Plate 7), the backwall was moved forward to within 0.5 ft of the suction bell; and the divider wall between the pump bays was made continuous from the backwall to the location of the 18-in.-diam column in the original design. This modification resulted in improved flow conditions at the pump intakes, but cross-flow through the upstream and open divider wall concentrated flow along one side of the pump bay during 1- and 2-pump operation. Pressure fluctuations and rotational flow indicators were higher than acceptable; prototype values are given in Table 2.

16. In the type 3 and 4 design sumps (Plate 7), the divider wall

was continuous so that crossflow would not occur during 1- or 2-pump operation. Significant decreases in rotational flow indicators, pressure fluctuations, and vortex formation were observed with the type 3 and 4 design sumps and 1-, 2-, and 3-pump operation. With the backwall 0.5 ft away from the pump bell (type 3 sump), pressure fluctuations were low, but rotational flow indicators and the tendency for vortex formation were higher than desired; thus, this design was not recommended for use in the prototype. Prototype values of pressure fluctuation and rotational flow indicators are given in Table 3 for the type 3 sump. With the backwall located 0.07 ft from the pump bell (type 4 sump), rotational flow indicators and tendency for vortex formation were low, but pressure fluctuations at the lower sump elevation were higher than desired for use in the prototype. In addition, too small a distance between the backwall and pump bell can affect pump efficiency (Chang 1977a). Prototype values of pressure fluctuation and rotational flow indicators are shown in Table 4 for the type 4 sump.

17. In the type 9 and 10 design sumps (Plate 8), the effects of the vertical gate and protruding gate slots were evaluated. Without the gates (type 9), flow conditions in the sump were significantly worse than in the type 3 or 4 sumps. Dye injected in the model showed that contraction of flow at the vertical gate had a stabilizing effect on flow approaching the pump intake. Recessing the gate slots (type 10 design sump) had no significant effect on flow at the pump intakes. Prototype values of pressure fluctuation and rotational flow indicators for the types 9 and 10 sumps are given in Tables 5 and 6, respectively.

18. Flow separation occurred at the upstream abutments and pier noses for most flow conditions, particularly with the lower water-surface elevations. Quadrant walls and rounded pier noses were added in the type 12 design sump (Plate 8) in an attempt to reduce flow separation. The separation was reduced, but no decrease in rotational flow indicators, pressure fluctuations, or tendency for vortex formation was observed in the model. Pressure fluctuations and rotational flow indicators are shown in Table 7.

19. Baffle walls were located upstream of the vertical gates in

the type 13 design sump (Plate 8). These walls were tested with the quadrant walls and the rounded pier noses and were intended to evenly distribute the flow approaching the pump intakes. Prototype values of pressure fluctuation and rotational flow indicators are given in Table 8. Adding the baffle walls resulted in relatively low values of rotational flow indicators and pressure fluctuation for the conditions shown in Table 8. However, turbulence and boiling action occurred in the area between the vertical gate and the pump, particularly at the lower sump elevation. The possible adverse effects of this turbulence are not known, and problems with sump clean-out would occur with the baffle walls. For these reasons the type 13 sump was not recommended for the prototype.

20. At this point in the study, emphasis was shifted from the sump to modifying the approach to the sump. The four different approaches tested with the type 3 sump are shown in Plate 9. In the type 2 approach the original (type 1) 1V-on-6H bottom slope was changed to a milder 1V-on-10H slope. Although no significant improvement was observed at the pump intakes, this modification was retained in subsequent designs because of the gradual approach it provided to the sump. Pressure fluctuations and rotational flow indicators for the type 3 sump using the type 2 (recommended) approach are shown in Table 9.

21. The original approach had a 1V-on-3H slope on the left side of the station (looking downstream) and a 1V-on-8H slope on the right side. In the type 3 approach, the right side was changed to a 1V-on-3H slope to correspond to the left side, and a short radius was used on both sides where the approach channel enters Blue Waters Ditch. Flow conditions within the sump were significantly improved with 50 percent flows from each direction. However, with 100 percent flow from right or left, conditions within the sump were not improved.

22. Long-radius vertical training walls were used in the type 4 approach in lieu of the sloped riprapped banks used in types 1-3 approaches. Flow conditions within the sump were excellent with 50 percent flows from each direction. However, 100 percent flow from right or left resulted in significant levels of rotational flow indicators,

pressure fluctuations, and a tendency for vortex formation.

23. A submerged rock dike was added to the vertical training walls in the type 5 approach, but it was not effective in straightening 100 percent flow from the left or right.

24. Further modifications of the sump were model-tested in an attempt to improve flow conditions. Trashracks blocking a large flow area were tested. Initial testing was conducted with trashracks blocking 33 percent of the flow area. These racks did not create enough restriction to distribute the flow evenly into the pump bays. The blockage was increased to 66 percent of the flow area in the type 25 design sump (Plate 10). These racks were effective in redistributing the flow into the sump. However, the head loss across the trashrack was 1 to 2 ft at sump el 396.0, and any trash buildup would greatly increase this loss and possibly cause operation problems. For this reason, the trashrack concept was not studied further.

25. Baffle blocks were tested in the model to determine their effectiveness in evenly distributing the flow approaching the pump intakes. The first blocks tested were 5 ft high and 2 ft wide and spaced 2 ft apart in two staggered rows. These blocks did not provide enough restriction to the flow. The blocks were enlarged to 11 ft high and 2 ft wide with a 2-ft spacing. These blocks were more effective in redistributing the flow, but rotational flow indicators and pressure fluctuations observed at the pump intakes were still considered too great. The blocks were enlarged to a width of 2.25 ft and spaced only 1.33 ft apart in the type 29 design sump (Plate 10). The quadrant wall was added on one side only to reduce the separation caused by flow across the 1V-on-8H slope of the right bank (looking downstream). These blocks were effective in redistributing the flow approaching the pumps for many of the operating conditions. However, sump el 396.0 and 100 percent flow from the right resulted in adverse pressure fluctuations and/or rotational flow indicators; prototype values are given in Table 10.

26. The St. Louis District has expressed concern over operational problems with the closely spaced baffle blocks. Clogging by debris and difficulty in cleaning the sump can be created by the blocks.

Recommended Design

27. Converging sidewalls and rounded pier noses were tested in the type 33 design sump (Plate 11, Figure 8). (Note that only the upstream distance (10.0 ft) and the sidewall and backwall clearance (0.5 ft) are given in Plate 11. The backwall distance is not given because the exact bell diameter dimension is not known until the pump selection has been made for the prototype. The backwall distance is determined after the exact bell diameter is known.) The type 33 sump resulted in the best flow conditions and overall hydraulic performance of all sump designs tested.

28. Pressure fluctuations and rotational flow indicators measured with this design sump are given in Table 11. A comparison of the pressure fluctuations and rotational flow indicators for the original and recommended designs are shown in Plates 12-17. Generally, the rotational flow indicators were less than 0.09 and pressure fluctuations were less than or equal to 3 ft of water. Minor surface depressions occurred intermittently in the model around the pump columns at the minimum sump el of 396.0 but are not considered sufficient to indicate severe vortices in the prototype. However, lowering the upstream vertical gate so that the bottom of the gate lip was at el 393.0 significantly reduced the presence of the surface depressions. Velocities in the recommended design sump for various operating conditions are shown in Plates 18-23.

29. In an attempt to improve upon the type 33 sump, further modifications were tested. Quadrant walls were added to the converging sidewall design in the type 34 design sump (Plate 11). These walls were intended to reduce separation at the upstream corners of the pump sump. The separation was reduced, but flow conditions at the pump intakes were not improved. Prototype values of pressure fluctuation and rotational flow indicators are given in Table 12.

30. The height of the pump bell above the floor was varied in the model. The height tested in the original and type 33 sumps was equal to 0.33 times the bell diameter above the sump floor. The bell

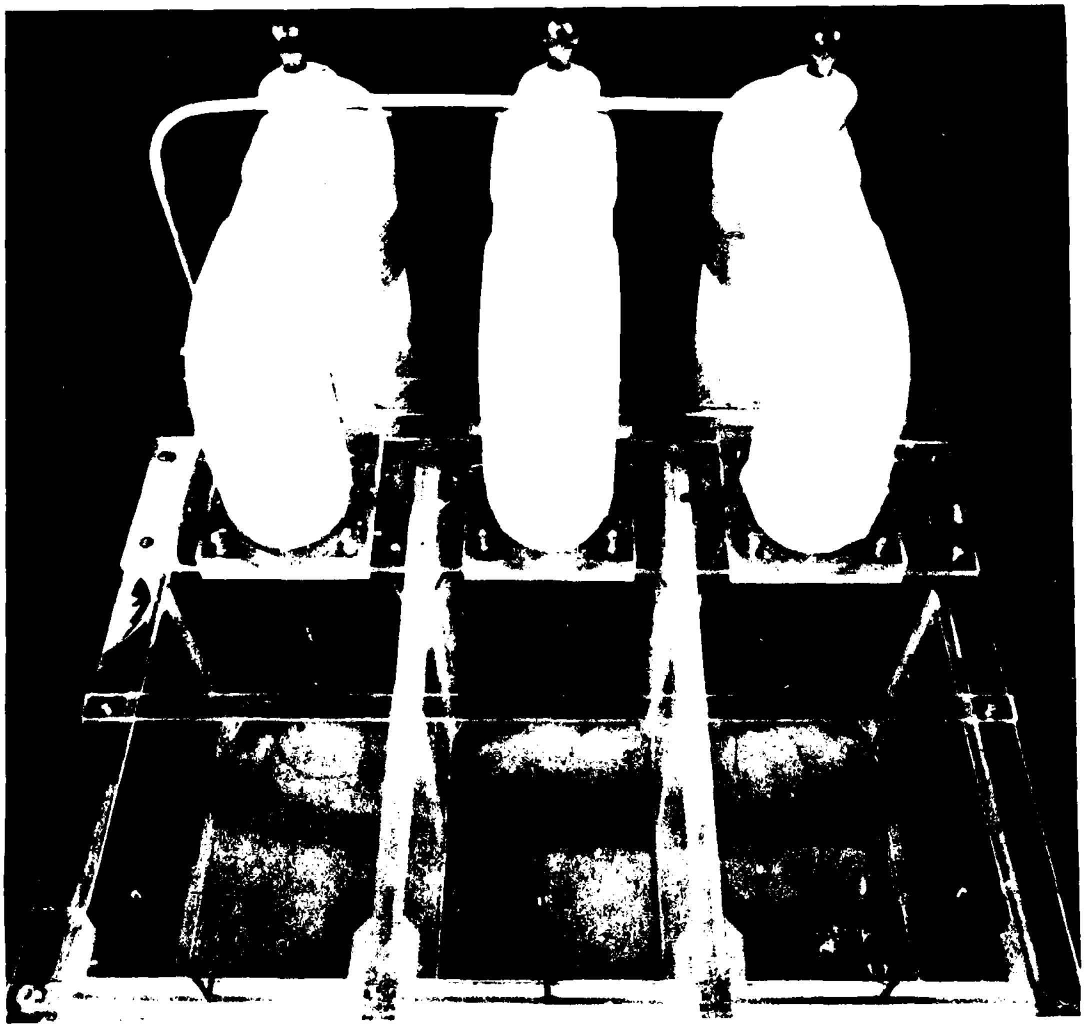


Figure 8. Converging sidewalls, type 33 design sump

was raised to a height of 0.48 times the bell diameter above the sump floor in the type 35 sump. Water levels within the sump remained the same, and raising the pump bell resulted in a decrease in the submergence of the pump. This resulted in decreased pressure fluctuations but increased the tendency for formation of the intermittent surface depressions. To maintain the same submergence, water depths within the sump would have to be increased the same amount as the pump bell was raised.

This could be accomplished either by raising the minimum operating levels in the station, which might adversely affect its operation, or by lowering the floor of the sump, which would increase cost. Maintaining maximum submergence and reducing the occurrence of the surface depressions were considered more important than the reduction in pressure fluctuations; therefore, a pump bell height of 0.33 times the bell diameter is recommended for the final design. Prototype values of pressure fluctuation and rotational flow indicators are shown in Table 13 for the type 35 sump design.

31. The effect on station performance of maintenance openings between the pump bays was tested with the type 37 design sump. These openings would be 2 ft wide by 5 ft high and would be located downstream of the vertical gates as shown in Plate 11. The openings were kept as small as possible to limit the amount of crossflow entering the pump bay when the adjacent pump(s) is not operating. Pressure fluctuations and rotational flow indicators for the design are given in Table 14. Pressure fluctuations were slightly greater, but rotational flow indicators remained the same as that observed with the type 33 sump.

32. Modifications to the approach (Plate 24) were tested in conjunction with the type 33 sump. The vertical approach walls (type 6 approach) worked well with 50 percent of the flow from each direction. However, 100 percent flow from right or left resulted in no improvement of sump flow conditions. Pressure fluctuations and rotational flow indicators are shown in Table 15. The riprap dike in the type 7 approach (Plate 24) was intended to break up the large eddies and to direct flow straight into the station. No improvement in flow conditions at the pump intakes was noted with the type 7 approach. Pressure fluctuations and rotational flow indicators are shown in Table 16 for the type 7 approach. The deepened approach (type 8) proposed by the St. Louis District did not result in improved flow conditions at the pump intakes either. Pressure fluctuations and rotational flow indicators are shown in Table 17 for the type 8 approach. Therefore, the recommended type 2 approach and the type 33 sump were retained.

Increased Velocities

33. A series of tests with increased velocities was conducted by observing the level of surface disturbance present around the pump columns and the type of vortices present for various operating conditions. The classification system for surface conditions is rather subjective, but no alternative was available. For surface conditions ranging from smooth to small ripples, the project engineer felt that the surface disturbance was not strong enough to significantly hinder the formation of vortices. For surface conditions of ripples, the effect of the surface disturbance was considered "borderline," and for rough conditions the surface disturbance was considered as definitely hindering the tendency for vortex formation. The classification of vortex types is illustrated in Figure 7.

34. Results of the tests are given in Table 18. At sump elevations of 396.0 and 398.0, the surface condition remained smooth or rippled up 2.0 to 2.25 times the Froudian velocities. Severe vortexing (type D or E) was present only at these lower sump elevations with velocities greater than 2.0 times Froudian. At sump el 399.5, the surface condition remained smooth or rippled up to 2.5 times the Froudian velocities, and no vortices or surface depressions were present at any of the increased velocities. At sump el 403.8, the surface condition remained smooth or rippled up to 3.0 times the Froudian velocities. Again, no vortices or surface depressions were present at any of the increased velocities.

35. These tests were conducted to obtain data for a range of increased velocities and operating combinations for future comparisons with prototype performance. Since vortex similarity is the prime consideration in using increased velocities, data concerning pressure fluctuations and rotational flow indicators were not taken in the increased velocity tests.

PART IV: DISCUSSION

36. The model indicated the need for modifications to the original design to improve flow conditions in the pump intakes. The first major hydraulic problem found within the sump was the crossflow between pump bays which was a result of the open divider wall configuration. This was eliminated by making the divider wall continuous. The second problem was caused by the relatively large distance between the pump bell and the backwall of the sump. This leaves a large area for circulation around the pump column which leads to significant rotation of the flow entering the pump bell and a greater tendency for vortex formation. The optimum suction bell location was found to be 0.5 ft upstream of the backwall. At closer positions, rotational flow indicators and the tendency for vortex formation were reduced, but pressure fluctuations were increased. With the suction bell located about 6.5 ft away from the backwall, pressure fluctuations were decreased, but rotational flow indicators and the tendency for vortex formation were increased.

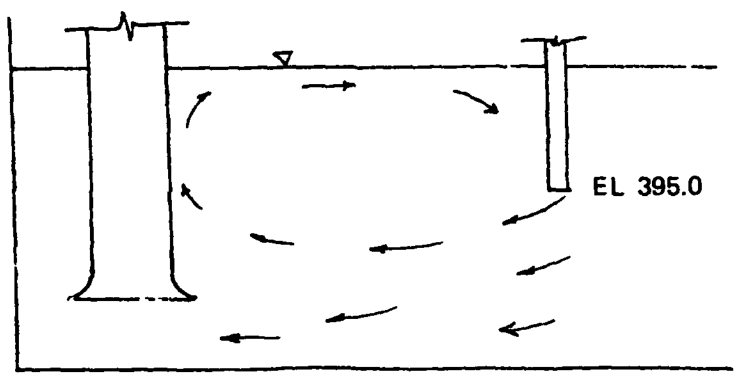
37. The third major hydraulic problem was the uneven distribution of flow entering the pump sump. Flow entering the pump sump must make a 90-deg change in direction in a relatively short distance. Surface current patterns, indicated by confetti, showed that the result of this abrupt change in flow direction was severe eddy action in front of the pump sump. These eddies concentrated flow on one side of the pump bay, and the uneven flow distribution continued downstream to the pump intakes. Guide vanes or dikes could solve this problem if flow entered the station from one direction only. However, with flows from either direction or any combination of flows from the two directions, development of a successful system of guide vanes or dikes is difficult. Contributing to this third major problem of uneven flow distribution were the nonsymmetrical abutments. It should be noted that none of the symmetrical abutment configurations tested in the model resulted in good performance with flow from one direction only. However, the concept of a symmetrical abutment was not pursued in detail because the St. Louis District expressed a need for the 1V-on-8H abutment slope on the right

side for vehicular access. Comparing pressure fluctuations and rotational flow indicators for 100 percent flow from the right and left did not indicate that one approach was more severe than the other.

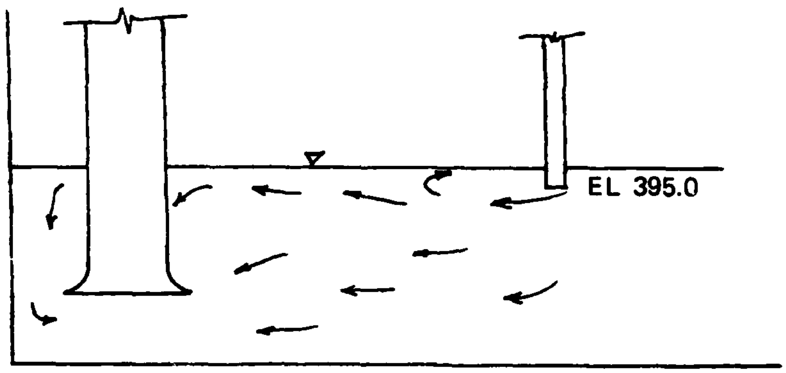
38. Baffle walls, baffle blocks, and restricted trashracks were tested in the pump sump to redistribute flow approaching the pumps. The restricted trashracks were successful but pose potential operational problems. Only the converging sidewalls were considered successful in improving flow conditions at the pump intakes without potential operational problems. The converging sidewalls reduced the uneven distribution of flow entering the pump intakes. In conjunction with the converging sidewalls, rounded pier noses and an approach slope of 1V on 10H are proposed for the recommended design. Pressure fluctuations were reduced from a maximum of 20 ft of water with the original design sump to 3 ft of water with the recommended design sump.

39. Minor surface depressions occurred with the recommended design sump at the minimum water-surface elevation of 396.0. These depressions were absent with higher water-surface elevations (399.5 and 403.8).

40. The upstream vertical gate caused flow to concentrate along the floor and created a roller at the higher water-surface elevations as shown below:



This roller produced a vertical upward velocity in the vicinity of the pump which tended to inhibit any vortex formation. These flow patterns were verified by dye injections in the model. Positioning the bottom of the vertical gate at the original elevation of 395.0 had little effect on outflow conditions with minimum water-surface levels as seen in the diagram below:



The roller was small, velocities in the vicinity of the pump were downward, and a greater tendency for circulation of flow and vortices existed. Lowering the gate lip down to el 393.0 tended to eliminate the surface depressions that occurred with the minimum water-surface elevations. The roller strength became large again, and velocities in the vicinity of the pump were directed upward to inhibit vortex formation. Alternate vertical gate locations at el 392.0 and el 394.0 were tested in the model, and gate elevations at or below el 392.0 resulted in significant head loss across the vertical gate and/or turbulence that resulted in large pressure fluctuations beneath the pump column. The vertical gate at el 394.0 did not significantly affect flow patterns, and no improvement in flow conditions was observed at the pump intakes. However, operation requiring that the vertical gate be extended down into a significant portion of the flow did have its drawbacks. The abrupt expansion introduced instabilities in the flow which could be seen by observing the fluctuating water surface in the model upstream of the pumps. The measured levels of rotational flow indicators and pressure fluctuation were slightly increased when the gate bottom was moved from the original location at el 395.0 down to el 393.0. Prototype testing at various gate bottom locations would provide valuable sump design guidance relative to the effects of an upstream vertical gate. This testing could include comparing pressure fluctuations, velocity distribution, and pump noise or vibration for various gate bottom elevations at various sump water levels. With either gate location, small floating debris which passed through the trashracks was trapped in front of the vertical gate.

41. Increased velocities were tested in the model and provide a basis for comparison with the prototype. With these increased velocities, the model pump sump is free of vortices up to velocities of 2.0 times the Froudian velocities for low water-surface elevations in the sump. The model was free of submerged vortices up to 3.0 times the Froudian velocities for the higher sump levels.

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Table 1

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 1 (Original) Design

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	10-	7	0.19	B
2	1, 2, 3			6+	3	0.11	B
3	1, 2, 3			13+	8	0.24	B
1	1, 3			6-	6	0.11	E
3	1, 3			10+	10	0.19	E
1	1, 2			4+	3	0.07	E
2	1, 2			5+	3	0.09	E
2	2, 3			9-	3	0.17	E
3	2, 3			1+	1	0.02	E
1	1			3+	1	0.06	E
2	2			1+	1	0.02	E
3	3			2-	1	0.04	E
1	1, 2, 3	100 R		5+	7	0.09	E
2	1, 2, 3			1-	3	0.02	--*
3	1, 2, 3			8+	9	0.15	D
1	1, 3			9-	8	0.17	E
3	1, 3			7+	11	0.13	E
1	1, 2			3+	11	0.06	E
2	1, 2			5+	3	0.09	E
2	2, 3			5-	5	0.09	E
3	2, 3			3+	1	0.06	E
1	1			3+	2	0.06	E
2	2			1+	1	0.02	E
3	3			1+	8	0.02	E
1	1, 2, 3	100 L		6-	7	0.11	E
2	1, 2, 3			11+	10	0.21	E
3	1, 2, 3			1+	8	0.02	D
1	1, 3			8-	5	0.15	E
3	1, 3			10+	10	0.19	E
1	1, 2			1+	3	0.02	E
2	1, 2			8+	5	0.15	E
2	2, 3			18-	7	0.34	E
3	2, 3			2-	6	0.04	E
1	1			1+	1	0.02	E
2	2			2-	1	0.04	E
3	3			1-	1	0.02	E
1	1, 2, 3	50-50	399.5	1-	6	0.02	--
2	1, 2, 3			2-	4	0.03	--
3	1, 2, 3			4-	13	0.07	--
1	1, 3			17-	12	0.28	--
3	1, 3			20+	14	0.33	--
1	1, 2			18-	15	0.30	A
2	1, 2			4-	8	0.07	--
2	2, 3			5+	7	0.08	A
3	2, 3			16+	15	0.27	A

(Continued)

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

(Sheet 1 of 3)

Table 1. (Continued)

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1	50-50	399.5	4-	5	0.07	E
2	2	50-50		1-	6	0.02	E
3	3	50-50		11+	4	0.18	E
1	1, 2, 3	100 R		3+	5	0.05	--*
2	1, 2, 3			2+	4	0.05	--
3	1, 2, 3			1+	14	0.02	--
1	1, 3			17-	15	0.28	--
3	1, 3			14+	14	0.23	B
1	1, 2			19-	11	0.32	A
2	1, 2			7-	5	0.12	D
2	2, 3			7+	5	0.12	A
3	2, 3			16+	14	0.27	A
1	1			5-	3	0.08	E
2	2			7-	7	0.12	E
3	3			8+	4	0.13	E
1	1, 2, 3	100 L		5-	15	0.08	--
2	1, 2, 3			9-	8	0.15	--
3	1, 2, 3			5-	14	0.08	--
1	1, 3			21-	15	0.35	A
3	1, 3			16+	14	0.27	A
1	1, 2			24-	15	0.40	B
2	1, 2			8-	6	0.13	A
2	2, 3			6+	7	0.10	A
3	2, 3			13+	14	0.22	A
1	1			7-	9	0.12	D
2	2			2-	4	0.03	E
3	3			8+	8	0.13	E
1	1, 2, 3	50-50	403.8	1-	7	0.02	--
2	1, 2, 3			1-	6	0.02	--
3	1, 2, 3			2-	6	0.03	--
1	1, 3			15-	13	0.25	--
3	1, 3			14+	13	0.23	--
1	1, 2			14-	13	0.23	--
2	1, 2			19-	11	0.32	A
2	2, 3			20+	10	0.33	--
3	2, 3			12+	13	0.20	--
1	1			16-	7	0.27	A
2	2			8-	4	0.13	C
3	3			17+	9	0.28	A
1	1, 2, 3	100 R		2+	5	0.03	--
2	1, 2, 3			1-	4	0.02	--
3	1, 2, 3			2+	13	0.03	--
1	1, 3			16-	17	0.27	--
3	1, 3			14+	18	0.23	--
1	1, 2			13-	14	0.22	--
2	1, 2			18-	10	0.30	A
2	2, 3			13+	12	0.22	--
3	2, 3			11+	13	0.18	--
1	1			8-	14	0.13	A
2	2			10-	4	0.17	A
3	3			15+	9	0.25	B
1	1, 2, 3	100 L		4-	12	0.07	--

(Continued)

* -- indicates that no surface vortices were observed.

(Sheet 2 of 3)

Table 1. *(Concluded)*

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
2	1, 2, 3	100 L	403.8	2-	5	0.03	--*
3	1, 2, 3			1-	5	0.02	--
1	1, 3			19-	19	0.32	--
3	1, 3			9+	20	0.15	--
1	1, 2			15-	15	0.25	--
2	1, 2			15-	11	0.25	A
2	2, 3			19+	13	0.32	A
3	2, 3			11+	8	0.18	--
1	1			14-	10	0.23	B
2	2			9-	4	0.15	A
3	3			16+	10	0.27	A

* -- indicates that no surface vortices were observed.

(Sheet 3 of 3)

Table 2

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 2 Sump, Type 1 (Original) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	4-	10	0.07	--*
2	1, 2, 3	50-50		2-	6	0.04	--
3	1, 2, 3	50-50		5+	2	0.09	--
1	1, 2, 3	100 L		6+	1	0.11	--
2	1, 2, 3	100 L		3+	5	0.06	--
3	1, 2, 3	100 L		3-	1	0.06	A
1	1	100 R		1-	3	0.02	A
1	1, 3	50-50	399.5	14-	10	0.23	A
3	1, 3	50-50		13+	5	0.22	A
1	1, 3	100 R		13-	9	0.22	A
3	1, 3	100 R		14+	3	0.23	A
1	1	100 L		8-	6	0.13	A
1	1, 3	100 R	403.8	17-	16	0.28	--
3	1, 3	100 R		19+	7	0.32	--
1	1, 3	100 L		17-	17	0.28	--
3	1, 3	100 L		19+	5	0.32	--
1	1	50-50		6+	10	0.10	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 3

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 3 Sump, Type 1 (Original) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	2+	3	0.04	--*
2	1, 2, 3			2+	2	0.04	--
3	1, 2, 3			6+	2	0.11	--
1	1, 3			1+	1	0.02	--
3	1, 3			3+	1	0.06	--
1	1, 2			1+	2	0.02	--
2	1, 2			2+	1	0.04	--
2	2, 3			4-	2	0.07	--
3	2, 3			4+	1	0.07	--
1	1			1-	1	0.02	A
2	2			2-	1	0.04	--
3	3			1-	1	0.02	A
1	1, 2, 3	100 R		1+	1	0.02	--
2	1, 2, 3			2-	1	0.04	--
3	1, 2, 3			3+	1	0.06	--
1	1, 3			4-	1	0.07	--
3	1, 3			1+	1	0.02	--
1	1, 2			5+	1	0.09	--
2	1, 2			1+	1	0.02	--
2	2, 3			1-	1	0.02	--
3	2, 3			1-	1	0.02	--
1	1			1+	2	0.02	--
2	2			7-	1	0.13	--
3	3			7-	3	0.13	--
1	1, 2, 3	100 L		8+	2	0.15	--
2	1, 2, 3			2+	1	0.04	--
3	1, 2, 3			3+	3	0.06	--
1	1, 3			6+	2	0.11	--
3	1, 3			5+	1	0.09	--
1	1, 2			7+	1	0.13	A
2	1, 2			1-	1	0.02	A
2	2, 3			6+	1	0.11	--
3	2, 3			4+	1	0.07	A
1	1			9+	2	0.17	--
2	2			6+	1	0.11	--
3	3			7+	1	0.13	--
1	1, 3	50-50	399.5	2+	1	0.03	--
3	1, 3	50-50		4-	2	0.07	--
1	1, 3	100 R		4-	1	0.07	--
3	1, 3	100 R		1-	1	0.02	--
1	1	100 L		10-	1	0.17	--
1	1, 3	100 R	403.8	1+	1	0.02	--
3	1, 3	100 R		5+	1	0.08	--
1	1, 3	100 L		3-	1	0.05	--
3	1, 3	100 L		1+	1	0.02	--
1	1	50-50		1+	1	0.02	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 4

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 4 Sump, Type 1 (Original) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	2-	5	0.03	--*
2	1, 2, 3	50-50		2+	1	0.03	--
3	1, 2, 3	50-50		1+	5	0.02	--
1	1, 2, 3	100 L		1+	3	0.02	--
2	1, 2, 3	100 L		4-	1	0.07	--
3	1, 2, 3	100 L		2-	3	0.03	--
1	1	100 R		1+	1	0.02	--
1	1, 3	50-50	399.5	2-	1	0.03	--
3	1, 3	50-50		1+	2	0.02	--
1	1, 3	100 R		1+	1	0.02	--
3	1, 3	100 R		1+	1	0.02	--
1	1	100 L		1+	1	0.02	--
1	1, 3	100 R	403.8	1+	1	0.02	--
3	1, 3	100 R		1+	1	0.02	--
1	1, 3	100 L		2-	1	0.03	--
3	1, 3	100 L		1+	1	0.02	--
1	1	50-50		1+	1	0.02	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 5

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 9 Sump, Type 1 (Original) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	4+	2	0.07	--*
2	1, 2, 3	50-50		3+	3	0.06	--
3	1, 2, 3	50-50		2+	1	0.04	--
1	1, 2, 3	100 L		3+	4	0.06	--
2	1, 2, 3	100 L		4+	3	0.07	--
3	1, 2, 3	100 L		9+	4	0.17	--
1	1	100 R		2-	2	0.04	--
1	1, 3	50-50	399.5	1-	3	0.02	--
3	1, 3	50-50		4+	1	0.07	--
1	1, 3	100 R		1-	3	0.02	--
3	1, 3	100 L		3+	1	0.05	--
1	1	100 L		1-	3	0.02	--
1	1, 3	100 R	403.8	2+	3	0.03	--
3	1, 3	100 R		8+	3	0.13	--
1	1, 3	100 L		1-	3	0.02	--
3	1, 3	100 L		2-	6	0.03	--
1	1	50-50		1-	3	0.02	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no survace vortices were observed.

Table 6

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 10 Sump, Type 1 (Original) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	1-	1	0.02	--*
2	1, 2, 3	50-50		1-	2	0.02	--
3	1, 2, 3	50-50		3+	1	0.06	--
1	1, 2, 3	100 L		4+	3	0.07	--
2	1, 2, 3	100 L		3+	3	0.06	--
3	1, 2, 3	100 L		1+	1	0.02	--
1	1	100 R		2-	3	0.04	--
1	1, 3	50-50	399.5	1-	2	0.02	--
3	1, 3	50-50		2-	1	0.03	--
1	1, 3	100 R		1-	1	0.02	--
3	1, 3	100 R		2-	1	0.03	--
1	1	100 L		1-	1	0.02	--
1	1, 3	100 R	403.8	1-	1	0.02	--
3	1, 3	100 R		1-	1	0.02	--
1	1, 3	100 L		5-	2	0.08	--
3	1, 3	100 L		1+	1	0.02	--
1	1	50-50		1+	1	0.02	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 7

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 12 Sump, Type 1 (Original) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	3-	4	0.06	--*
2	1, 2, 3	50-50		1-	2	0.02	--
3	1, 2, 3	50-50		5+	2	0.09	--
1	1, 2, 3	100 L		5+	3	0.09	--
2	1, 2, 3	100 L		5-	3	0.09	--
3	1, 2, 3	100 L		1-	2	0.02	--
1	1	100 R		1+	2	0.02	--
1	1, 3	50-50	399.5	5-	4	0.08	--
3	1, 3	50-50		1-	1	0.02	--
1	1, 3	100 R		1-	1	0.02	--
3	1, 3	100 R		1-	1	0.02	--
1	1	100 L		1-	1	0.02	--
1	1, 3	100 R	403.8	3-	1	0.05	--
3	1, 3	100 R		2+	1	0.03	--
1	1, 3	100 L		7-	2	0.12	--
3	1, 3	100 L		1-	1	0.02	--
1	1	50-50		1+	1	0.02	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 8

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 13 Sump, Type 1 (Original) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	2+	1	0.04	--*
2	1, 2, 3	50-50		3+	2	0.06	--
3	1, 2, 3	50-50		1-	2	0.02	--
1	1, 2, 3	100 L		3+	2	0.06	--
2	1, 2, 3	100 L		2-	2	0.04	--
3	1, 2, 3	100 L		2-	1	0.04	--
1	1	100 R		1+	1	0.02	--
1	1, 3	50-50	399.5	2-	2	0.03	--
3	1, 3	50-50		1-	1	0.02	--
1	1, 3	100 R		1-	1	0.02	--
3	1, 3	100 R		1-	1	0.02	--
1	1	100 L		1-	1	0.02	--
1	1, 3	100 R	403.8	1+	1	0.02	--
3	1, 3	100 R		1+	1	0.02	--
1	1, 3	100 L		3-	1	0.05	--
3	1, 3	100 L		1+	1	0.02	--
1	1	50-50		1+	1	0.02	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 9

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 3 Sump, Type 2 (Recommended) Approach

Pump	Pumps Operating	flow; - Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational flow; - Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	4-	2	0.07	--*
2	1, 2, 3	50-50		2-	1	0.04	--
3	1, 2, 3	50-50		7+	1	0.13	--
1	1, 2, 3	100 L		7+	1	0.13	--
2	1, 2, 3	100 L		2+	1	0.04	--
3	1, 2, 3	100 L		5-	1	0.09	--
1	1	100 R		2+	1	0.04	--
1	1, 3	50-50	399.5	1-	1	0.02	--
3	1, 3	50-50		4-	1	0.07	--
1	1, 3	100 R		2-	1	0.03	--
3	1, 3	100 R		1-	1	0.02	--
1	1	100 L		1-	1	0.02	--
1	1, 3	100 R	403.8	1+	1	0.02	--
3	1, 3	100 R		2+	1	0.03	--
1	1, 3	100 L		1-	1	0.02	--
3	1, 3	100 L		2+	1	0.03	--
1	1	50-50		1+	1	0.02	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 10

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 29 Sump, Type 2 (Recommended) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	1+	1	0.02	--*
2	1, 2, 3			3-	2	0.06	--
3	1, 2, 3			1-	1	0.02	--
1	1, 3			6+	1	0.11	--
3	1, 3			5-	2	0.09	--
1	1, 2			1+	1	0.02	--
2	1, 2			2-	1	0.04	--
2	2, 3			6-	4	0.11	--
3	2, 3			2-	1	0.04	--
1	1			4+	1	0.07	--
2	2			5-	2	0.09	--
3	3			5-	2	0.09	--
1	1, 2, 3	100 R		4-	4	0.07	--
2	1, 2, 3			7-	3	0.13	--
3	1, 2, 3			1-	1	0.02	--
1	1, 3			1-	1	0.02	--
3	1, 3			5-	3	0.09	--
1	1, 2			2-	3	0.04	--
2	1, 2			2-	1	0.04	--
2	2, 3			10-	5	0.19	--
3	2, 3			4-	2	0.07	--
1	1			1-	1	0.02	--
2	2			8-	2	0.15	--
3	3			11-	5	0.21	A
1	1, 2, 3	100 L		1-	1	0.02	--
2	1, 2, 3			1-	1	0.02	--
3	1, 2, 3			1+	1	0.02	--
1	1, 3			1-	2	0.02	--
3	1, 3			5-	2	0.09	--
1	1, 2			1+	1	0.02	--
2	1, 2			2+	1	0.04	--
2	2, 3			3-	2	0.06	--
3	2, 3			3-	2	0.06	--
1	1			1+	3	0.02	--
2	2			1-	1	0.02	--
3	3			7-	3	0.13	--
1	1, 3	50-50	399.5	2+	1	0.03	--
3	1, 3	50-50		2+	1	0.03	--
1	1, 3	100 R		1+	1	0.02	--
3	1, 3	100 R		1-	1	0.02	--
1	1	100 L		2+	1	0.03	--
1	1, 3	100 R	403.8	1+	1	0.02	--
3	1, 3	100 R		1+	1	0.02	--
1	1, 3	100 L		1+	1	0.02	--
3	1, 3	100 L		1-	1	0.02	--
1	1	50-50		1+	1	0.02	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 11

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 33 (Recommended) Sump, Type 2 (Recommended) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	2-	2	0.04	--*
2	1, 2, 3			1+	1	0.02	--
3	1, 2, 3			4+	1	0.07	--
1	1, 3			1-	2	0.02	--
3	1, 3			3+	1	0.06	--
1	1, 2			1-	2	0.02	--
2	1, 2			3+	1	0.06	--
2	2, 3			3-	2	0.06	--
3	2, 3			3+	1	0.06	--
1	1			1+	1	0.02	--
2	2			2-	1	0.04	--
3	3			2-	1	0.04	--
1	1, 2, 3	100 R		1+	2	0.02	--
2	1, 2, 3			1-	1	0.02	--
3	1, 2, 3			3+	1	0.06	--
1	1, 3			1+	1	0.02	--
3	1, 3			3+	1	0.06	--
1	1, 2			1+	2	0.02	--
2	1, 2			3+	1	0.06	--
2	2, 3			1+	1	0.02	--
3	2, 3			3+	1	0.06	--
1	1			1+	2	0.02	--
2	2			3-	2	0.06	--
3	3			1-	2	0.02	--
1	1, 2, 3	100 L		2+	1	0.04	--
2	1, 2, 3			2-	2	0.04	--
3	1, 2, 3			4+	1	0.07	--
1	1, 3			1+	2	0.02	--
3	1, 3			3+	1	0.06	--
1	1, 2			1+	2	0.02	--
2	1, 2			2-	1	0.04	--
2	2, 3			2-	1	0.04	--
3	2, 3			1-	2	0.02	--
1	1			1-	2	0.02	--
2	2			2-	2	0.04	--
3	3			1-	1	0.02	--
1	1, 2, 3	50-50	399.5	5+	2	0.08	--
2	1, 2, 3			4-	1	0.07	--
3	1, 2, 3			6-	2	0.10	--
1	1, 3			2-	1	0.03	--
3	1, 3			2+	1	0.03	--
1	1, 2			1-	2	0.02	--
2	1, 2			4-	1	0.07	--
2	2, 3			2+	2	0.03	--
3	2, 3			1-	2	0.02	--

(Continued)

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

(Sheet 1 of 3)

Table 11. (Continued)

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1	50-50	399.5	1-	2	0.02	--*
2	2	50-50		1-	3	0.02	--
3	3	50-50		3+	1	0.05	--
1	1, 2, 3	100 R		1-	1	0.02	--
2	1, 2, 3			1-	1	0.02	--
3	1, 2, 3			1-	2	0.02	--
1	1, 3			4-	2	0.07	--
3	1, 3			2+	1	0.03	--
1	1, 2			1+	1	0.02	--
2	1, 2			5-	1	0.08	--
2	2, 3			3+	2	0.05	--
3	2, 3			1-	2	0.02	--
1	1			2-	2	0.03	--
2	2			2-	2	0.03	--
3	3			4-	3	0.07	--
1	1, 2, 3	100 L		1-	2	0.02	--
2	1, 2, 3			5-	2	0.08	--
3	1, 2, 3			5-	2	0.08	--
1	1, 3			4-	1	0.07	--
3	1, 3			1-	2	0.02	--
1	1, 2			1-	2	0.02	--
2	1, 2			5-	2	0.08	--
2	2, 3			4-	1	0.07	--
3	2, 3			2-	2	0.03	--
1	1			5-	1	0.08	--
2	2			5-	1	0.08	--
3	3			3+	3	0.05	--
1	1, 2, 3	50-50	403.8	1-	1	0.02	--
2	1, 2, 3			1-	1	0.02	--
3	1, 2, 3			3+	2	0.05	--
1	1, 3			2-	2	0.03	--
3	1, 3			1-	2	0.02	--
1	1, 2			1-	1	0.02	--
2	1, 2			1+	2	0.02	--
2	2, 3			1-	1	0.02	--
3	2, 3			1-	2	0.02	--
1	1			1+	2	0.02	--
2	2			1+	2	0.02	--
3	3			2+	2	0.03	--
1	1, 2, 3	100 R		1+	2	0.02	--
2	1, 2, 3			1-	2	0.02	--
3	1, 2, 3			2+	2	0.03	--
1	1, 3			1+	2	0.02	--
3	1, 3			1+	2	0.02	--
1	1, 2			1-	2	0.02	--
2	1, 2			2-	1	0.03	--
2	2, 3			1+	2	0.02	--
3	2, 3			1-	1	0.02	--
1	1			1-	1	0.02	--
2	2			2-	2	0.03	--

(Continued)

* -- indicates that no surface vortices were observed.

Table 11. (Concluded)

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
3	3	100 R	403.8	1-	2	0.02	--*
1	1, 2, 3	100 L		1-	1	0.02	--
2	1, 2, 3			1-	1	0.02	--
3	1, 2, 3			2-	1	0.03	--
1	1, 3			2-	1	0.03	--
3	1, 3			4+	2	0.07	--
1	1, 2			1+	1	0.02	--
2	1, 2			1+	2	0.02	--
2	2, 3			1+	1	0.02	--
3	2, 3			6+	3	0.10	--
1	1			3+	1	0.05	--
2	2			2+	3	0.03	--
3	3			6+	3	0.10	--

* -- indicates that no surface vortices were observed.

(Sheet 3 of 3)

Table 12

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 34 Sump, Type 2 (Recommended) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	399.5	4-	1	0.07	--*
2	1, 2, 3			1-	1	0.02	--
3	1, 2, 3			1-	1	0.02	--
2	2			7-	2	0.12	--
2	2, 3	100 R		2+	1	0.03	--
3	2, 3	100 R		3-	1	0.05	--
3	3	100 L		11+	4	0.18	--
1	1, 2, 3			3-	1	0.05	--
2	1, 2, 3			7-	2	0.12	--
3	1, 2, 3			5-	3	0.08	--
1	1			6-	1	0.10	--
2	2			5+	3	0.08	--
3	3		403.8	9+	4	0.15	--
2	2, 3			1-	2	0.02	--
3	3			1-	2	0.02	--
2	2			1+	3	0.03	--
3	3			2+	3	0.03	

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 13

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 35 Sump, Type 2 (Recommended) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	4-	1	0.07	--*
2	1, 2, 3			2-	1	0.04	--
3	1, 2, 3			6+	1	0.11	--
1	1, 3			3-	1	0.06	--
3	1, 3			3+	1	0.06	--
1	1, 2			2-	1	0.04	--
2	1, 2			3+	1	0.06	--
2	2, 3			5-	1	0.09	--
3	2, 3			4+	1	0.07	--
1	1			2-	1	0.04	--
2	2			3-	1	0.06	--
3	3			2-	1	0.04	--
1	1, 2, 3	100 R		2+	1	0.04	--
2	1, 2, 3			3+	1	0.06	--
3	1, 2, 3			1+	1	0.02	--
1	1, 3			1-	1	0.02	--
3	1, 3			2+	1	0.04	--
1	1, 2			1+	1	0.02	--
2	1, 2			4+	1	0.07	--
2	2, 3			1+	1	0.02	--
3	2, 3			3+	1	0.06	--
1	1			1+	1	0.02	--
2	2			3-	1	0.06	--
3	3			1+	1	0.02	--
1	1, 2, 3	100 L		2+	1	0.04	--
2	1, 2, 3			5-	1	0.09	--
3	1, 2, 3			1+	1	0.02	--
1	1, 3			1-	1	0.02	--
3	1, 3			1+	1	0.02	--
1	1, 2			1+	1	0.02	--
2	1, 2			2-	1	0.04	--
2	2, 3			1-	1	0.02	--
3	2, 3			1+	1	0.02	--
1	1			1-	1	0.02	--
2	2			2-	1	0.04	--
3	3			2-	1	0.04	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 14

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 37 Sump, Type 2 (Recommended) Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	2-	2	0.04	--*
2	1, 2, 3			1-	2	0.02	--
3	1, 2, 3			6+	2	0.11	--
1	1, 3			1-	2	0.02	--
3	1, 3			3+	2	0.06	--
1	1, 2			1-	2	0.02	--
2	1, 2			1-	1	0.02	--
2	2, 3			2-	2	0.04	--
3	2, 3			3+	2	0.06	--
1	1			1-	2	0.02	--
2	2			1-	1	0.02	--
3	3			1+	2	0.02	--
1	1, 2, 3	100 R		1+	2	0.02	--
2	1, 2, 3			1+	1	0.02	--
3	1, 2, 3			4+	1	0.07	--
1	1, 3			1-	3	0.02	--
3	1, 3			2-	2	0.04	--
1	1, 2			1-	2	0.02	A
2	1, 2			1+	1	0.02	--
2	2, 3			1-	3	0.02	--
3	2, 3			2+	1	0.04	--
1	1			2-	2	0.04	--
2	2			1-	4	0.02	--
3	3			1-	3	0.02	--
1	1, 2, 3	100 L		1+	1	0.02	--
2	1, 2, 3			1-	2	0.02	--
3	1, 2, 3			1+	2	0.02	--
1	1, 3			1+	2	0.02	--
3	1, 3			4+	2	0.07	--
1	1, 2			1+	1	0.02	--
2	1, 2			3-	1	0.06	--
2	2, 3			2+	1	0.04	--
3	2, 3			3+	1	0.06	--
1	1			1-	2	0.02	--
2	2			1+	1	0.02	--
3	3			4+	1	0.07	--
1	1, 2, 3	50-50	399.5	1-	2	0.02	--
2	1, 2, 3			3-	2	0.05	--
3	1, 2, 3			7-	2	0.12	--
1	1, 3			1-	2	0.02	--
3	1, 3			5-	2	0.08	--
1	1, 2			2-	1	0.03	--
2	1, 2			5-	2	0.08	--
2	2, 3			1-	2	0.02	--
3	2, 3			5-	1	0.08	--

(Continued)

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

(Sheet 1 of 3)

Table 14. (Continued)

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1	50-50	399.5	1-	3	0.02	--*
2	2	50-50		3-	2	0.05	--
3	3	50-50		6-	2	0.10	--
1	1, 2, 3	100 R		3+	2	0.05	--
2	1, 2, 3			3-	2	0.05	--
3	1, 2, 3			6-	2	0.10	--
1	1, 3			2-	2	0.03	--
3	1, 3			5-	2	0.08	--
1	1, 2			1+	2	0.02	--
2	1, 2			3-	1	0.05	--
2	2, 3			5-	2	0.08	--
3	2, 3			3-	2	0.05	--
1	1			1+	2	0.02	--
2	2			3-	4	0.05	--
3	3			5-	2	0.08	--
1	1, 2, 3	100 L		1-	2	0.02	--
2	1, 2, 3			5-	2	0.08	--
3	1, 2, 3			4-	2	0.07	--
1	1, 3			2-	2	0.03	--
3	1, 3			1-	3	0.02	--
1	1, 2			2-	2	0.03	--
2	1, 2			1-	1	0.02	--
2	2, 3			2-	2	0.03	--
3	2, 3			1-	2	0.02	--
1	1			4-	2	0.07	--
2	2			4+	1	0.07	--
3	3			6+	2	0.10	--
1	1, 2, 3	50-50	403.8	1-	2	0.02	--
2	1, 2, 3			2-	1	0.03	--
3	1, 2, 3			1-	1	0.02	--
1	1, 3			1-	2	0.02	--
3	1, 3			2-	2	0.03	--
1	1, 2			1-	2	0.02	--
2	1, 2			1-	1	0.02	--
2	2, 3			3-	2	0.05	--
3	2, 3			1-	2	0.02	--
1	1			1-	2	0.02	--
2	2			1-	2	0.02	--
3	3			1-	2	0.02	--
1	1, 2, 3	100 R		2+	2	0.03	--
2	1, 2, 3			1-	1	0.02	--
3	1, 2, 3			1+	2	0.02	--
1	1, 3			1+	2	0.02	--
3	1, 3			1-	3	0.02	--
1	1, 2			1-	1	0.02	--
2	1, 2			1-	1	0.02	--
2	2, 3			1-	3	0.02	--
3	2, 3			2-	2	0.03	--
1	1			2-	2	0.03	--
2	2			2-	3	0.03	--

(Continued)

* -- indicates that no surface vortices were observed.

(Sheet 2 of 3)

Table 14. (Concluded)

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
3	3	100 R	403.8	2-	3	0.03	--*
1	1, 2, 3	100 L		2-	2	0.03	--
2	1, 2, 3			2-	2	0.03	--
3	1, 2, 3			1-	1	0.02	--
1	1, 3			1-	2	0.02	--
3	1, 3			1-	2	0.02	--
1	1, 2			1+	2	0.02	--
2	1, 2			2-	1	0.03	--
2	2, 3			2-	2	0.03	--
3	2, 3			1-	2	0.02	--
1	1			1-	2	0.02	--
2	2			2-	2	0.03	--
3	3			3-	3	0.05	--

* -- indicates that no surface vortices were observed.

(Sheet 3 of 3)

Table 15

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 33 (Recommended), Type 6 Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	1-	1	0.02	--*
2	1, 2, 3			3-	1	0.06	--
3	1, 2, 3			3-	1	0.06	--
1	1, 3			1-	1	0.02	A
3	1, 3			1-	2	0.02	A
1	1, 2			3-	1	0.06	--
2	1, 2			1+	1	0.02	--
2	2, 3			3-	1	0.06	--
3	2, 3			2-	2	0.04	--
1	1			1-	2	0.02	A
2	2			2-	1	0.04	--
3	3			1+	1	0.02	--
1	1, 2, 3	100 R		1-	2	0.02	--
2	1, 2, 3			2-	2	0.04	--
3	1, 2, 3			5-	2	0.09	--
1	1, 3			1-	3	0.02	--
3	1, 3			1+	2	0.02	--
1	1, 2			2-	2	0.04	--
2	1, 2			2-	1	0.04	--
2	2, 3			3-	1	0.06	--
3	2, 3			4-	2	0.07	--
1	1			1-	2	0.02	A
2	2			1-	1	0.02	A
3	3			1+	2	0.02	--
1	1, 2, 3	100 L		6+	3	0.11	--
2	1, 2, 3			1+	1	0.02	A
3	1, 2, 3			5+	2	0.09	--
1	1, 3			1-	1	0.02	--
3	1, 3			3+	1	0.06	A
1	1, 2			2+	1	0.04	A
2	1, 2			3+	2	0.06	--
2	2, 3			2+	2	0.04	A
3	2, 3			3+	1	0.06	--
1	1			4+	2	0.07	A
2	2			3+	2	0.06	--
3	3			1+	1	0.02	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 16

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 33 (Recommended) Sump, Type 7 Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	6-	3	0.11	A
2	1, 2, 3			1-	1	0.02	--*
3	1, 2, 3			3+	1	0.06	--
1	1, 3			3-	3	0.06	A
3	1, 3			1+	1	0.02	--
1	1, 2			3-	3	0.06	--
2	1, 2			2+	1	0.04	--
2	2, 3			3-	1	0.06	--
3	2, 3			1+	1	0.02	--
1	1			1-	3	0.02	--
2	2			1-	2	0.02	--
3	3			1-	1	0.02	--
1	1, 2, 3	100 R		1+	2	0.02	--
2	1, 2, 3			1-	1	0.02	--
3	1, 2, 3			3+	1	0.06	--
1	1, 3			1-	3	0.02	--
3	1, 3			1+	1	0.02	--
1	1, 2			1+	1	0.02	--
2	1, 2			2+	1	0.04	--
2	2, 3			1+	1	0.02	--
3	2, 3			2+	1	0.04	--
1	1			1-	2	0.02	--
2	2			1-	1	0.02	--
3	3			1+	1	0.02	--
1	1, 2, 3	100 L		1+	1	0.02	--
2	1, 2, 3			1+	1	0.02	--
3	1, 2, 3			1-	1	0.02	--
1	1, 3			1+	1	0.02	--
3	1, 3			1+	1	0.02	--
1	1, 2			1+	1	0.02	--
2	1, 2			1-	2	0.02	--
2	2, 3			2-	1	0.04	--
3	2, 3			1-	1	0.02	--
1	1			1-	1	0.02	--
2	2			1-	2	0.02	--
3	3			1+	1	0.02	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 17

Pressure Fluctuations, Rotational Flow Indicators, and Surface Vortices at Pump Intakes, Type 33 (Recommended) Sump, Type 8 Approach

Pump	Pumps Operating	Flow Direction Percent	Sump Elevation ft, NGVD	Vortimeter Rotations rpm	Pressure Fluctuation ft of Water	Rotational Flow Indicator R_i	Surface Vortices
1	1, 2, 3	50-50	396.0	4-	4	0.07	A
2	1, 2, 3			1+	1	0.02	--*
3	1, 2, 3			3+	1	0.06	--
1	1, 3			2-	3	0.04	A
3	1, 3			1+	2	0.02	--
1	1, 2			4-	4	0.07	--
2	1, 2			2+	1	0.04	--
2	2, 3			1-	1	0.02	--
3	2, 3			1-	2	0.02	--
1	1			2-	2	0.04	--
2	2			1-	2	0.02	--
3	3			1-	2	0.02	--
1	1, 2, 3	100 R		1+	2	0.02	--
2	1, 2, 3			1+	1	0.02	--
3	1, 2, 3			2-	1	0.04	--
1	1, 3			1-	4	0.02	--
3	1, 3			2+	1	0.04	--
1	1, 2			1+	2	0.02	--
2	1, 2			2+	2	0.04	--
2	2, 3			1-	1	0.02	--
3	2, 3			1+	1	0.02	--
1	1			3-	3	0.06	--
2	2			1-	1	0.02	--
3	3			1-	3	0.02	--
1	1, 2, 3	100 L		2-	3	0.04	--
2	1, 2, 3			1-	1	0.02	--
3	1, 2, 3			1+	1	0.02	--
1	1, 3			2-	4	0.04	--
3	1, 3			2+	1	0.04	--
1	1, 2			3-	4	0.06	--
2	1, 2			1-	2	0.02	--
2	2, 3			3-	1	0.06	--
3	2, 3			1+	1	0.02	--
1	1			1+	1	0.02	--
2	2			2+	2	0.04	--
3	3			1+	1	0.02	--

Note: All magnitudes are expressed in terms of prototype equivalents. Discharge per pump = 200 cfs at sump el 396.0 and 225 cfs at sump el 399.5 and 403.8; + = clockwise rotational flow; - = counterclockwise rotational flow; surface vortices severity as illustrated in Figure 7.

* -- indicates that no surface vortices were observed.

Table 18

Surface Conditions and Vortex Types at Pump Columns with Increased Velocities,

Type 23 (Recommended) Sump, Type 2 (Recommended) Approach

Test No.	Pumps Operating	Flow Direction	Sump Elevation ft, NGVD	Velocity × Froudian	Surface Condition	Vortex Type
1	1, 2, 3	50-50	396.0	1.0	Smooth	Intermittent surface depression
				1.5	Smooth	A
				2.0	Small ripples	B-C
				2.25	Ripples	C-D
2	1, 2, 3	50-50	399.5	1.0	Smooth	None
				1.5	Smooth	None
				2.0	Small ripples	None
				2.25	Small ripples	None
3	1, 2, 3	50-50	403.8	1.0	Smooth	None
				1.5	Smooth	None
				2.0	Small ripples	None
				2.25	Small ripples	None
4	3	100 R	396.0	1.0	Smooth	None
				1.5	Small ripples	A
				2.0	Ripples	B
				2.5	Rough	D
				3.0	Rough	D
5	3	100 R	399.5	1.0	Smooth	None
				1.5	Smooth	None
				2.0	Small ripples	None
				2.5	Ripples	None
				3.0	Rough	None
				3.67 (Prototype)	Rough	None
6	6	100 R	403.8	1.0	Smooth	None
				1.5	Smooth	None
				2.0	Smooth	None
				2.5	Small ripples	None
				3.0	Ripples	None
				3.67 (Prototype)	Rough	None
7	1, 2, 3	50-50	398.0	1.0	Smooth	None
				1.5	Smooth	Intermittent surface depression
				2.0	Ripples	A
				2.5	Rough	B
8	1, 2	50-50	396.0	1.0	Smooth	Intermittent surface depression
				1.5	Smooth	B
				2.0	Small ripples	C
				2.5	Ripples	D
				3.0	Rough	D-E

(Continued)

Table 18 (Concluded)

Test No.	Pumps Operating	Flow Direction	Sump Elevation ft, NGVD	Velocity × Froudian	Surface Condition	Vortex Type
9	1, 2	50-50	398.0	1.0	Smooth	None
				1.5	Smooth	A
				2.0	Small ripples	A
				2.5	Rough	B
				3.0	Rough	B
10	3	50-50	396.0	1.0	Smooth	None
				1.5	Smooth	A
				2.0	Small ripples	C
				2.5	Rough	D
				3.0	Rough	D-E
11	3	50-50	398.0	1.0	Smooth	None
				1.5	Smooth	None
				2.0	Small Ripples	A
				2.5	Ripples	B-C
				3.0	Rough	C
12	3	100 R		1.0	Smooth	None
				1.5	Smooth	Intermittent surface depression
				2.0	Small ripples	A
				2.5	Ripples	B-C
				3.0	Rough	D

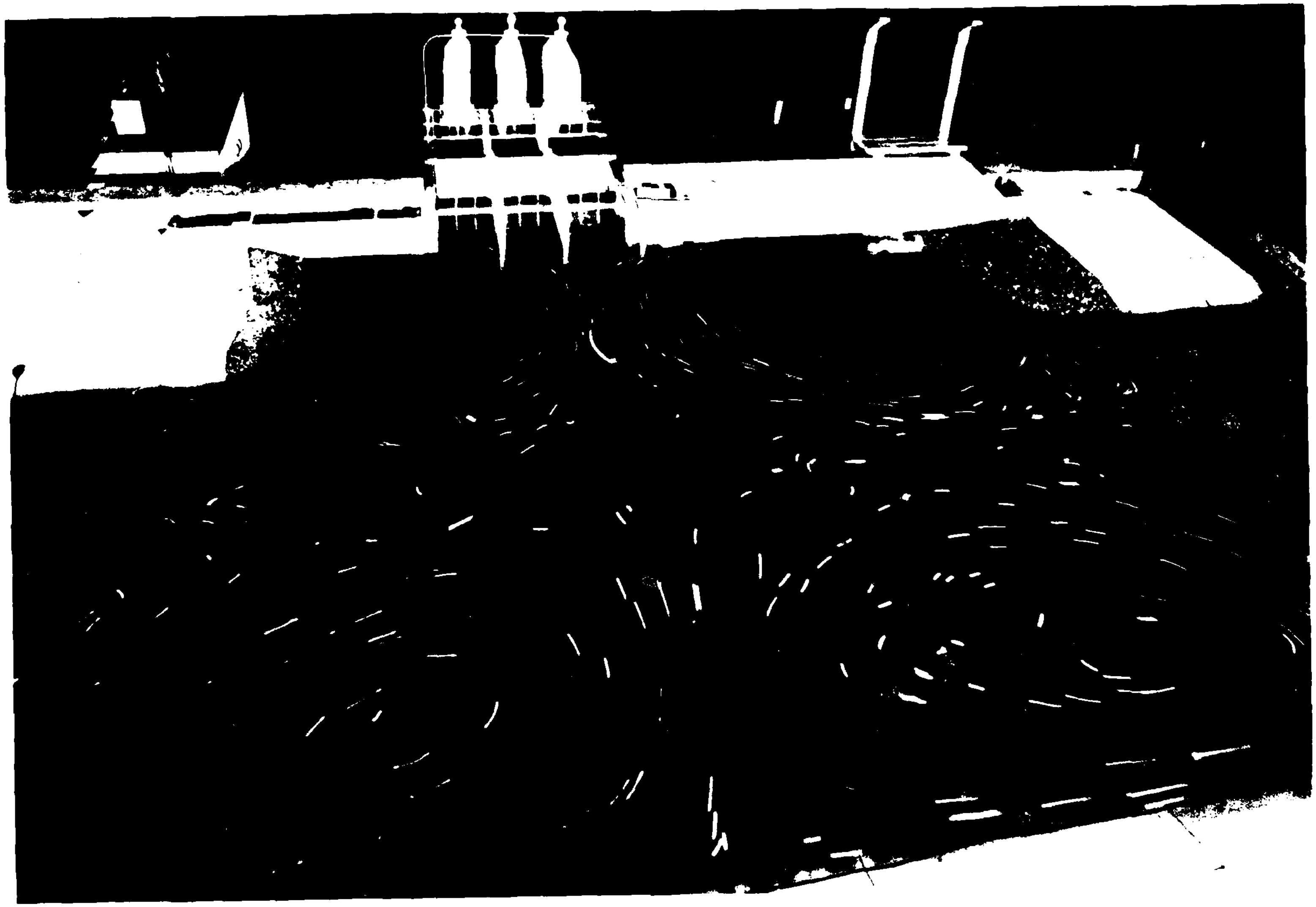


Photo 1. Type 1 (original) sump; sump el 396.0, pumps 1, 2, 3 operating, flow 50 percent left-50 percent right

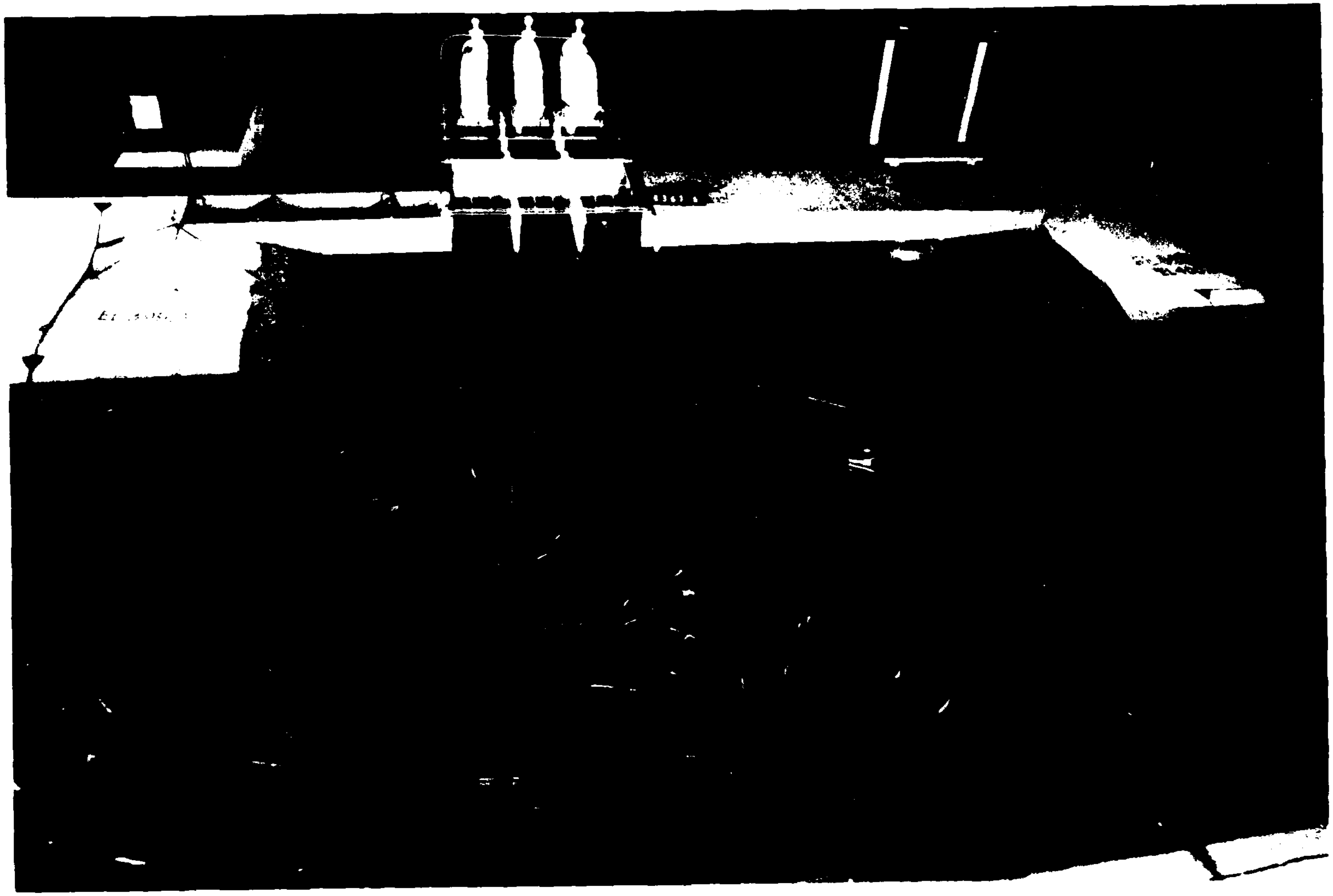


Photo 2. Type 1 (original) sump; sump el 396.0, pumps 1, 2, 3 operating, flow 100 percent right

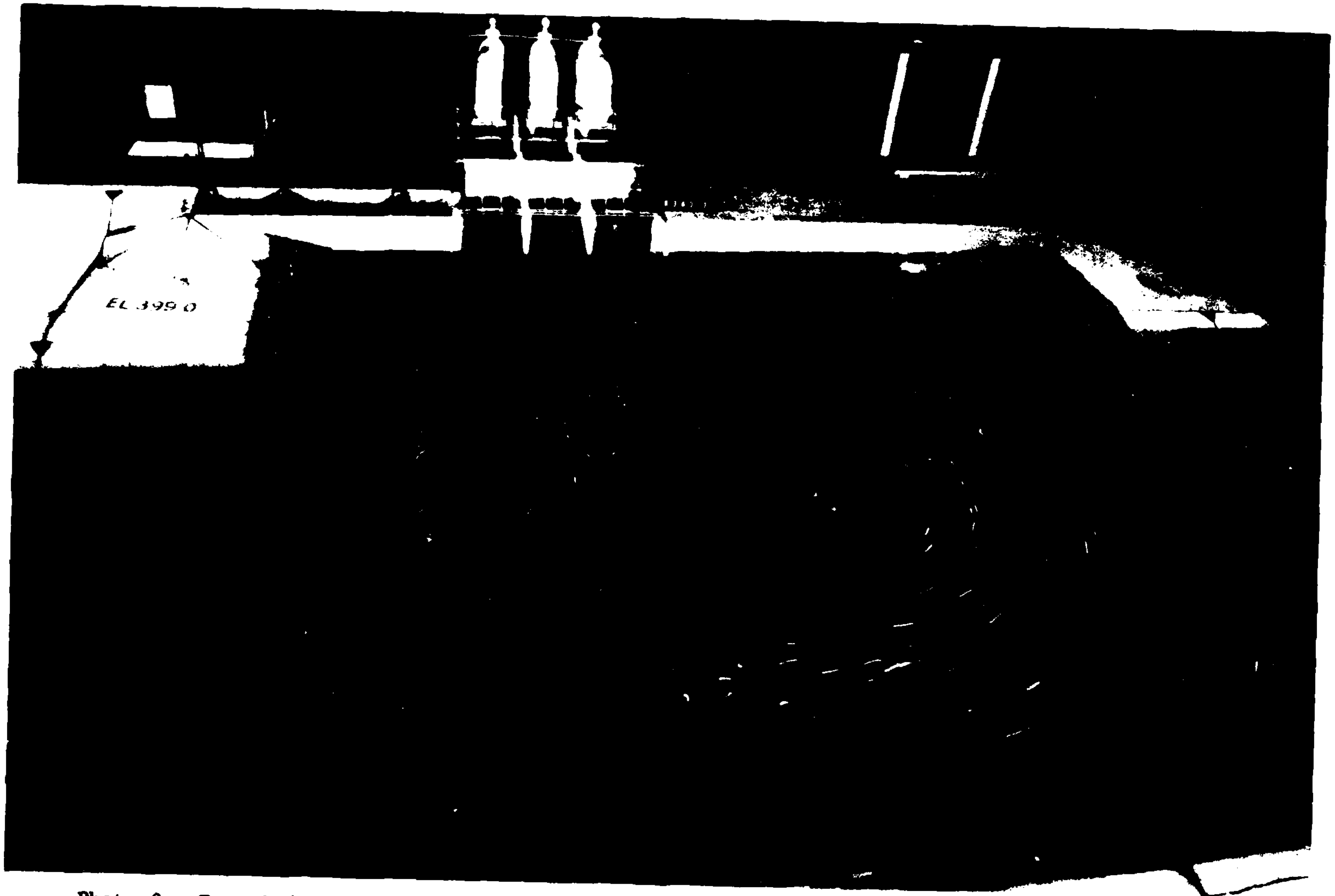


Photo 3. Type 1 (original) sump; sump el 396.0, pumps 1, 2, 3 operating, flow 100 percent left

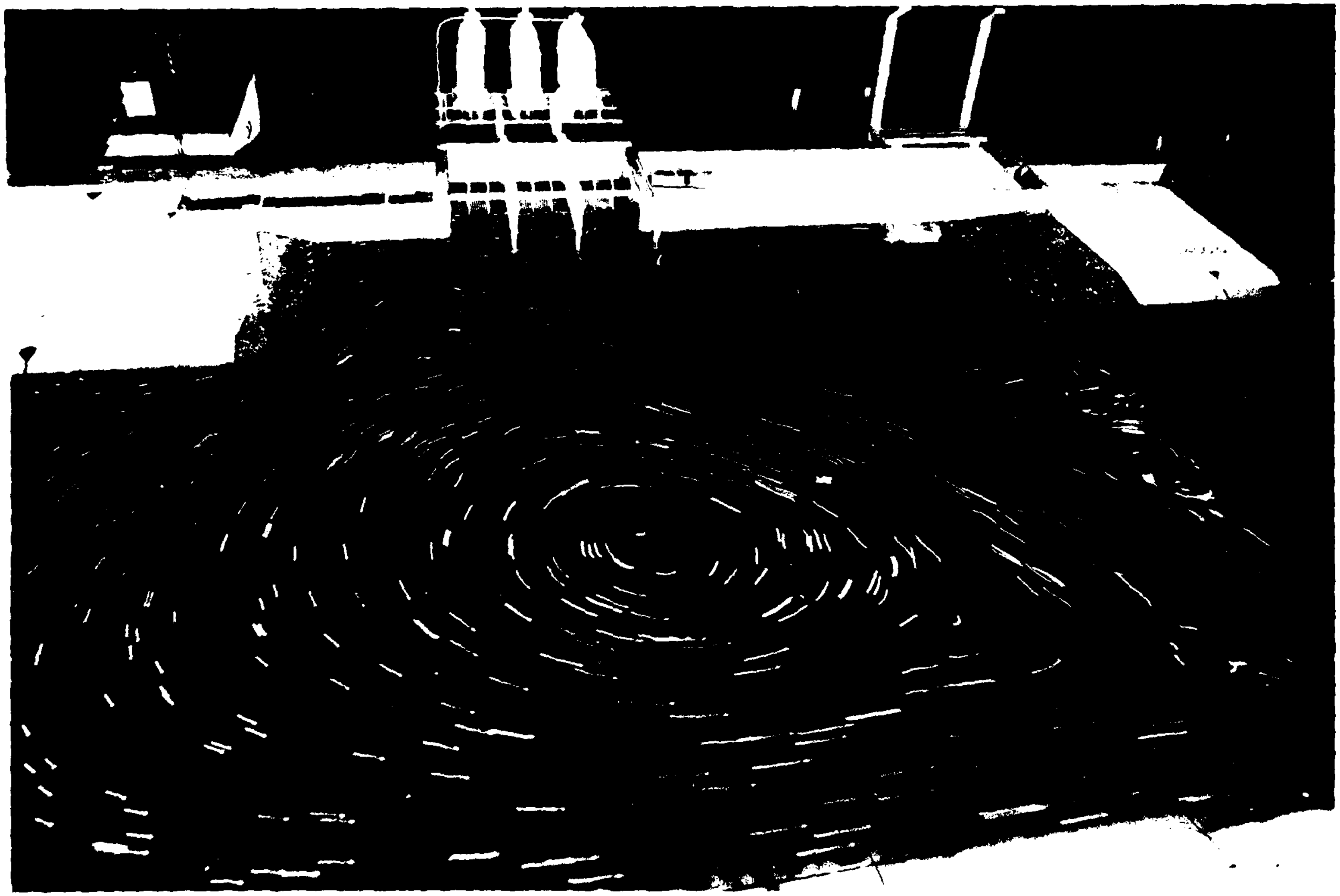


Photo 4. Type 1 (original) sump; sump el 396.0, pumps 1, 2 operating, flow *100* percent right

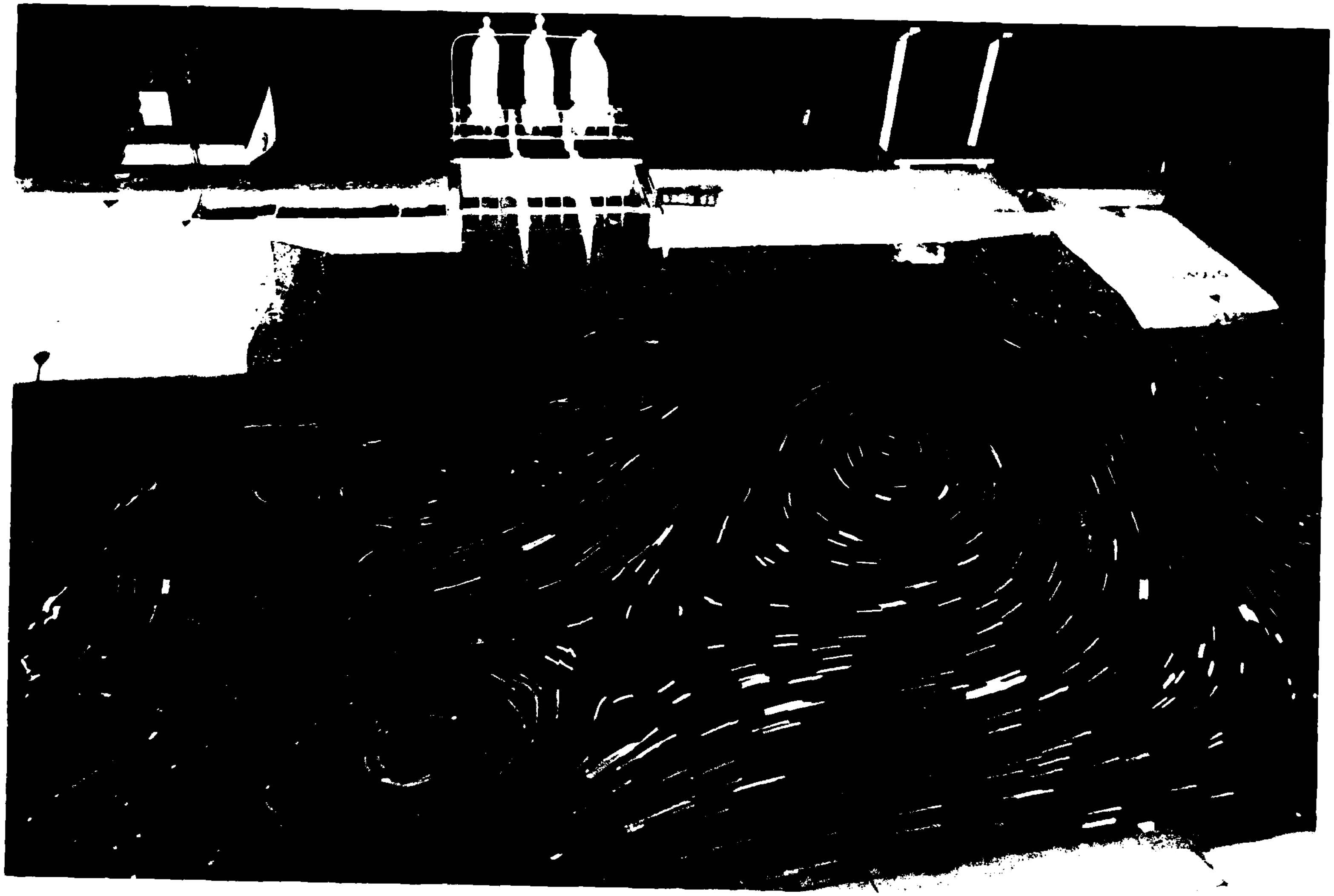


Photo 5. Type 1 (original) sump; sump el 396.0, pumps 1, 2 operating, flow 100 percent left

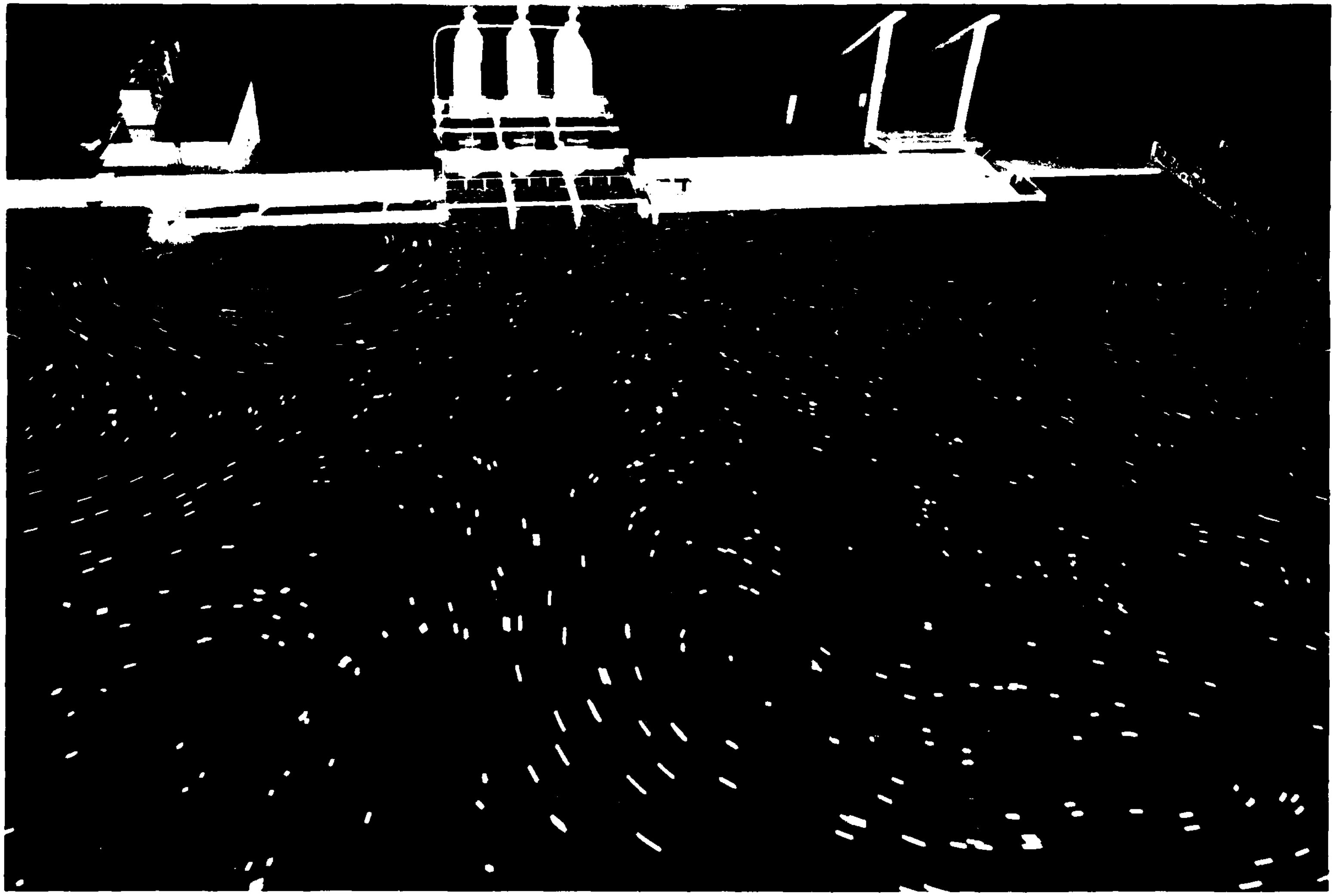


Photo 6. Type 1 (original) sump; sump el 403.8, pumps 1, 2, 3 operating, flow 50 percent left-50 percent right

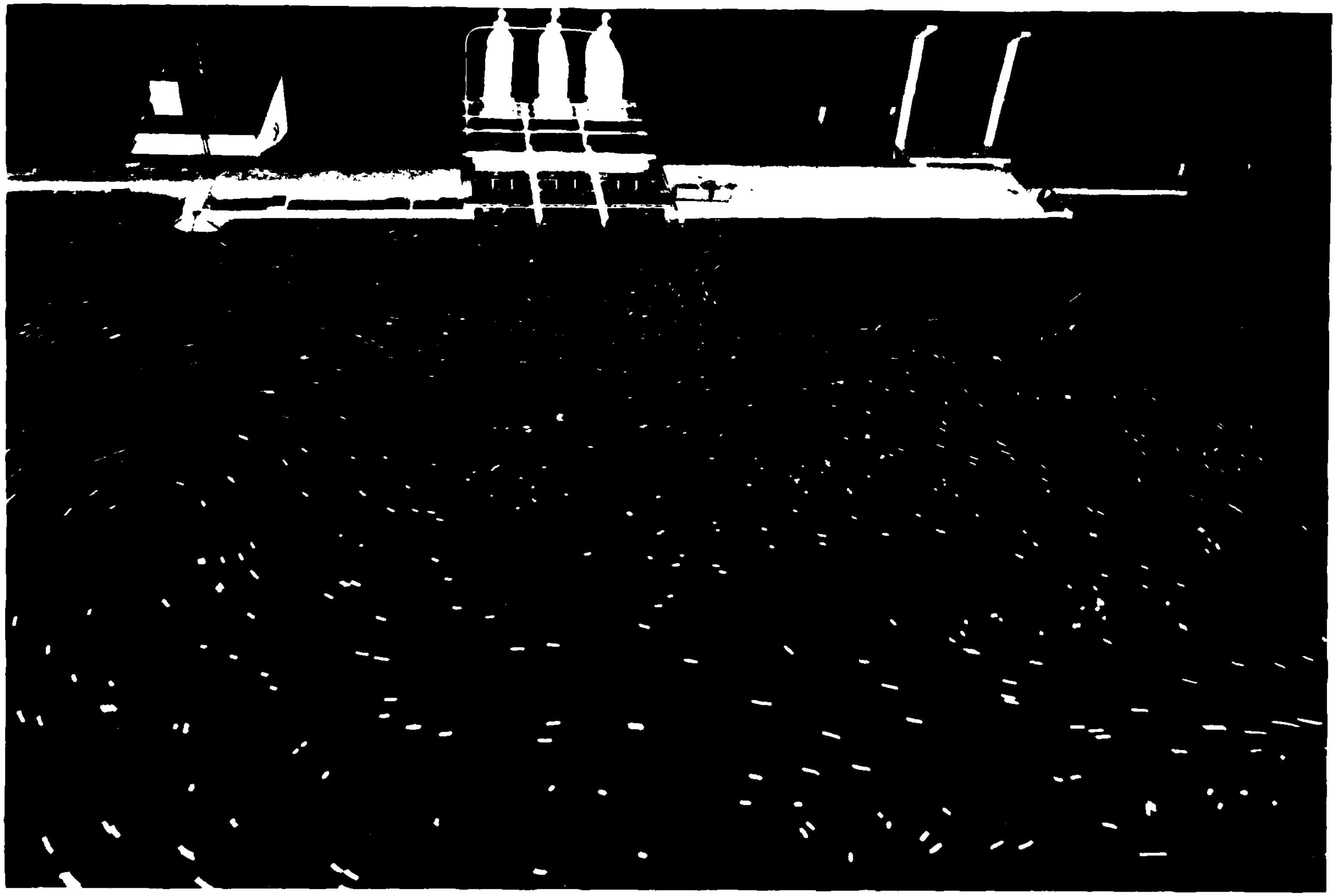


Photo 7. Type 1 (original) sump; sump el 403.8, pumps 1, 2, 3 operating, flow 100 percent right

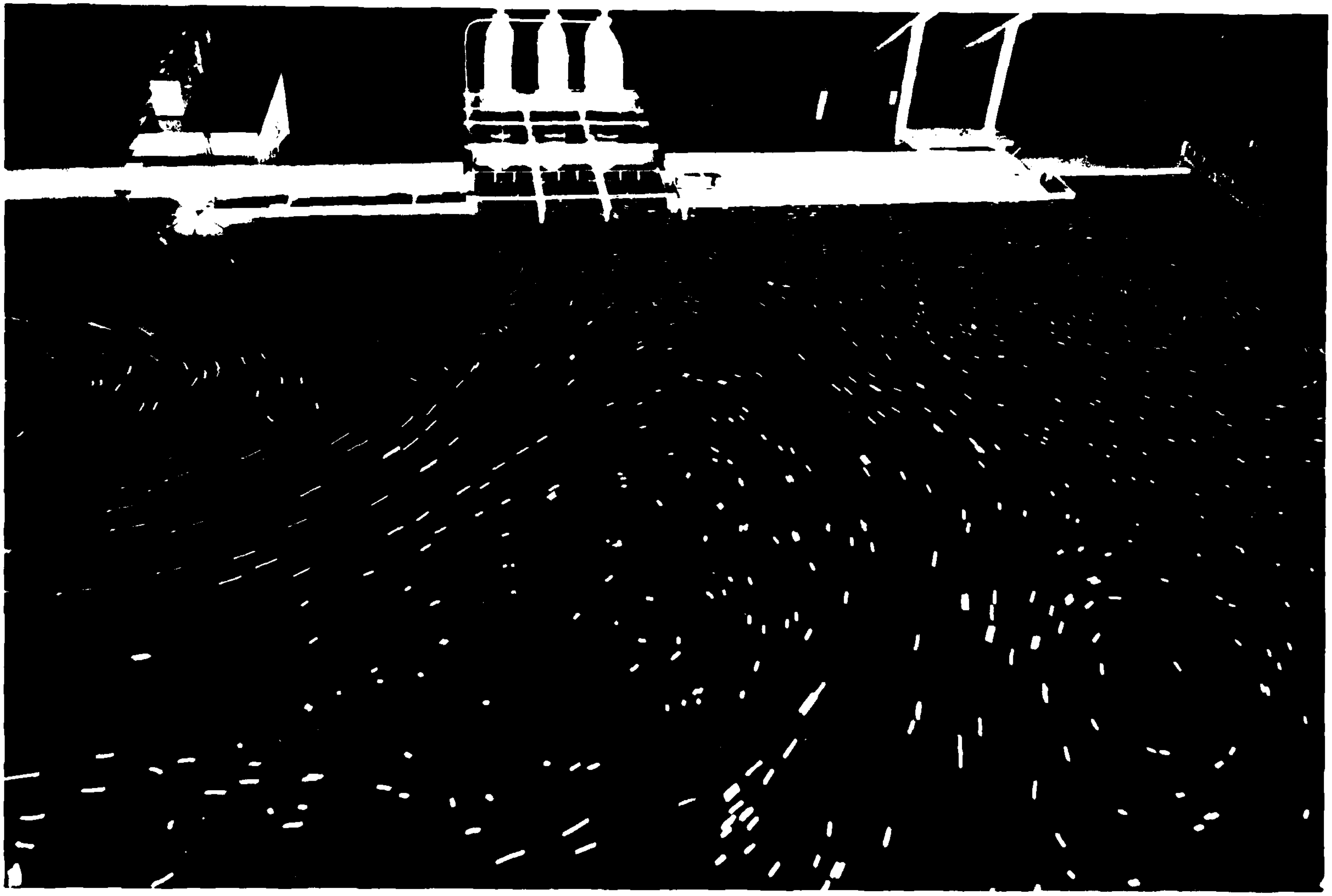


Photo 8. Type 1 (original) sump; sump el 403.8, pumps 1, 2, 3 operating, flow 100 percent left

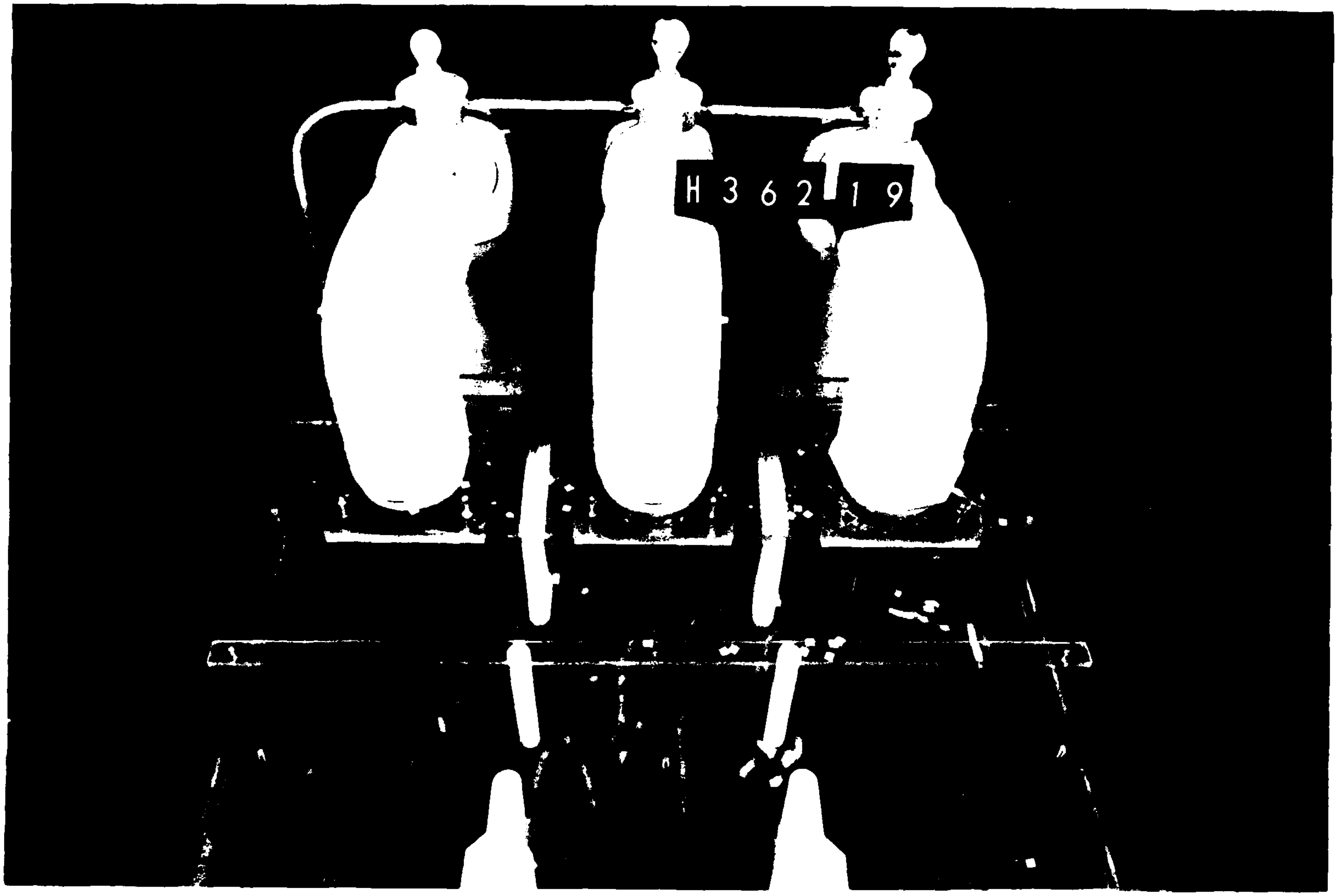


Photo 9. Type 1 (original) sump; sump el 396.0, pumps 1, 2, 3 operating, flow 50 percent left-50 percent right

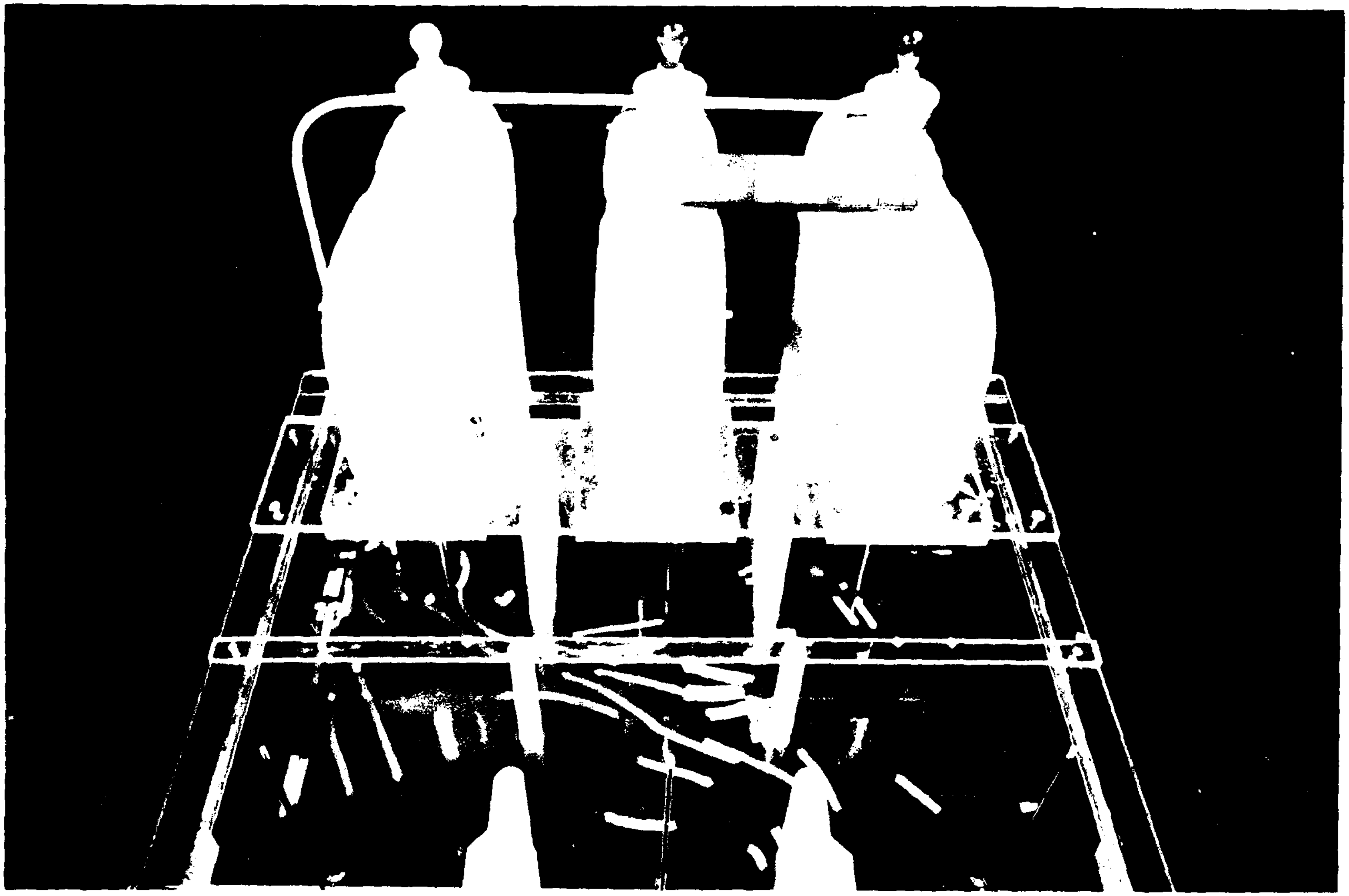


Photo 10. Type 1 (original) sump; sump el 396.0, pump 1 operating, flow 50 percent left-50 percent right

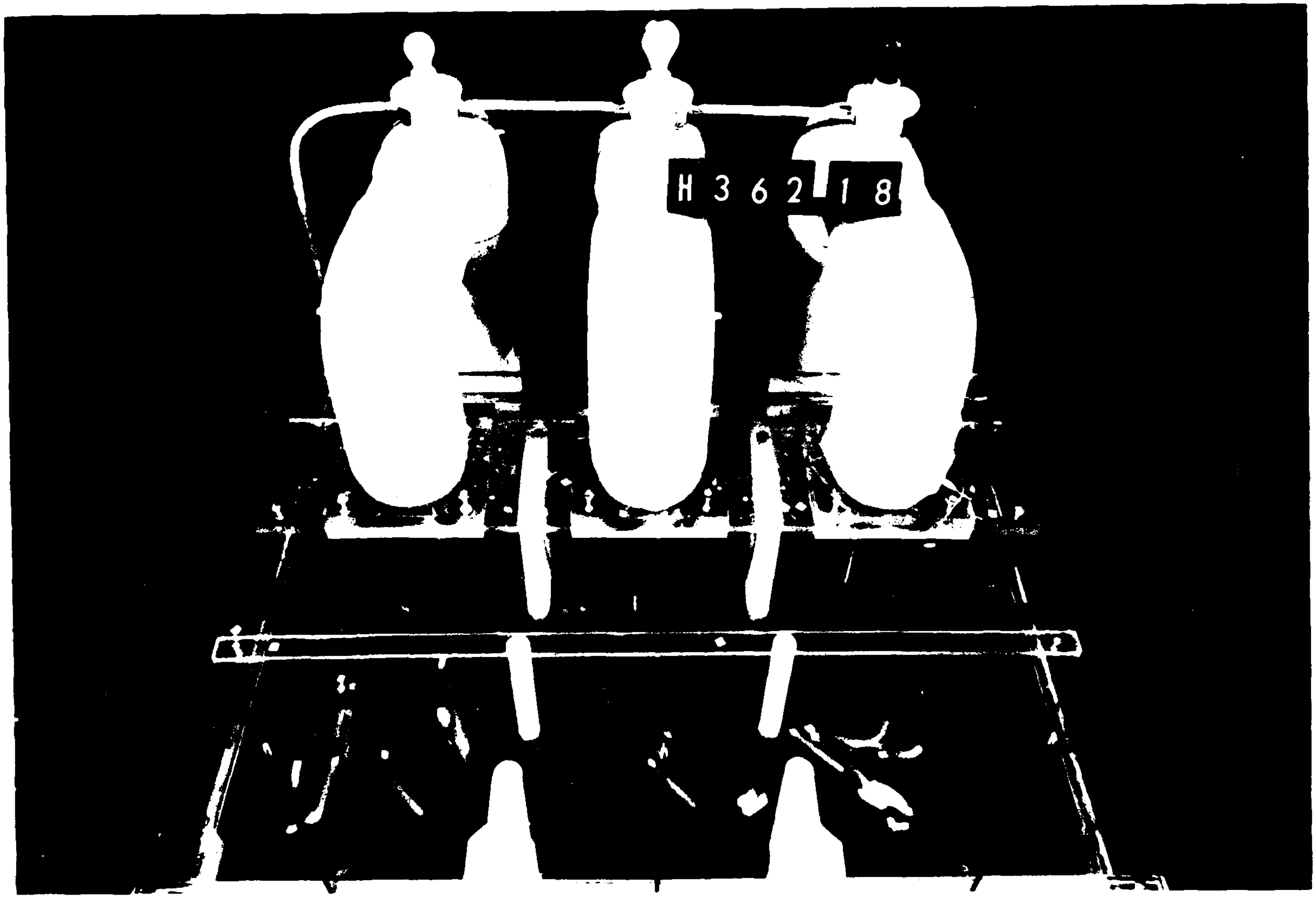


Photo 11. Type 1 (original) sump; sump el 396.0, pumps 1, 2 operating, flow 50 percent left-50 percent right

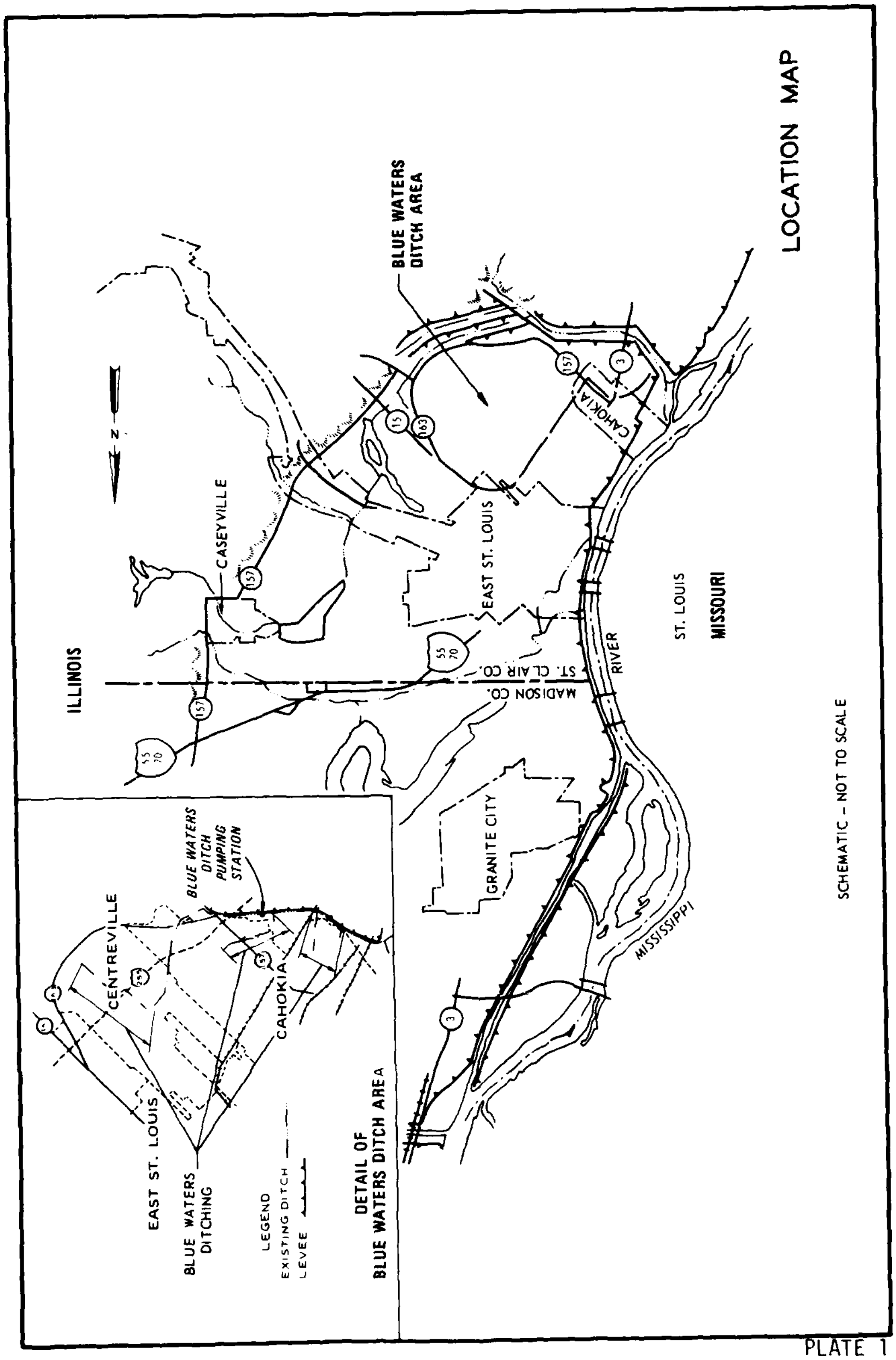
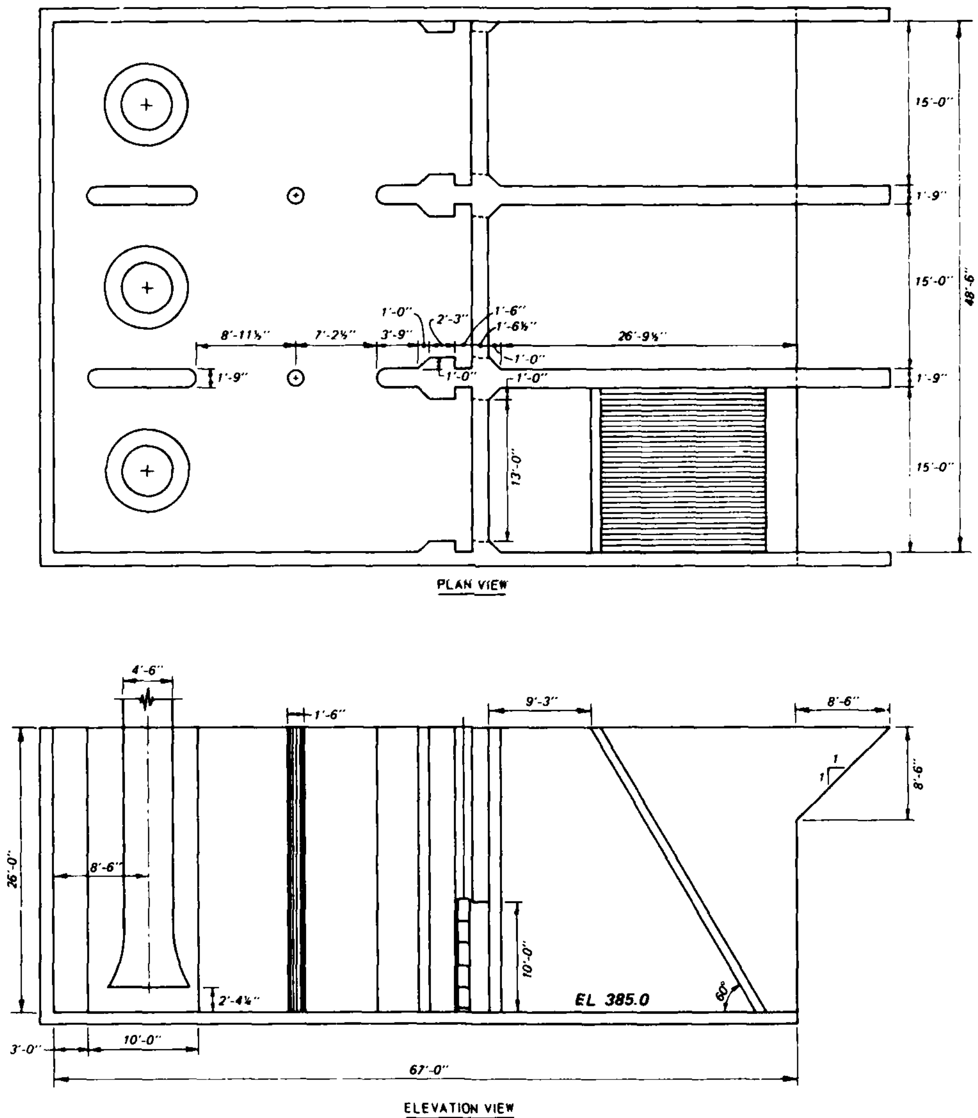
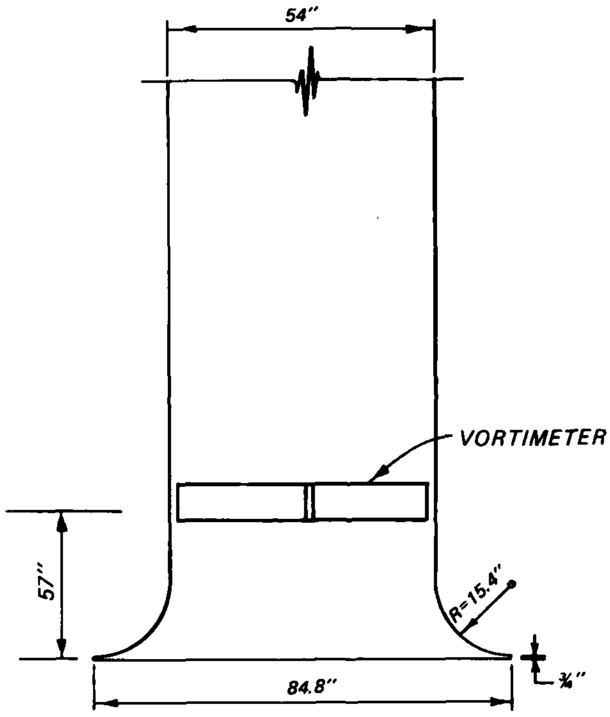

LOCATION MAP
BLUE WATERS DITCH AREA
N
ILLINOIS
CASEYVILLE
EAST ST. LOUIS
CAHOKIA
ST. CLAIR CO.
MADISON CO.
RIVER
ST. LOUIS
MISSOURI
GRANITE CITY
MISSISSIPPI
SCHEMATIC – NOT TO SCALE
157
55 70
15
163
3
CENTREVILLE
BLUE WATERS DITCH PUMPING STATION
EAST ST. LOUIS
BLUE WATERS DITCHING
CAHOKIA
LEGEND
EXISTING DITCH
LEVEE
DETAIL OF BLUE WATERS DITCH AREA

PLATE 1



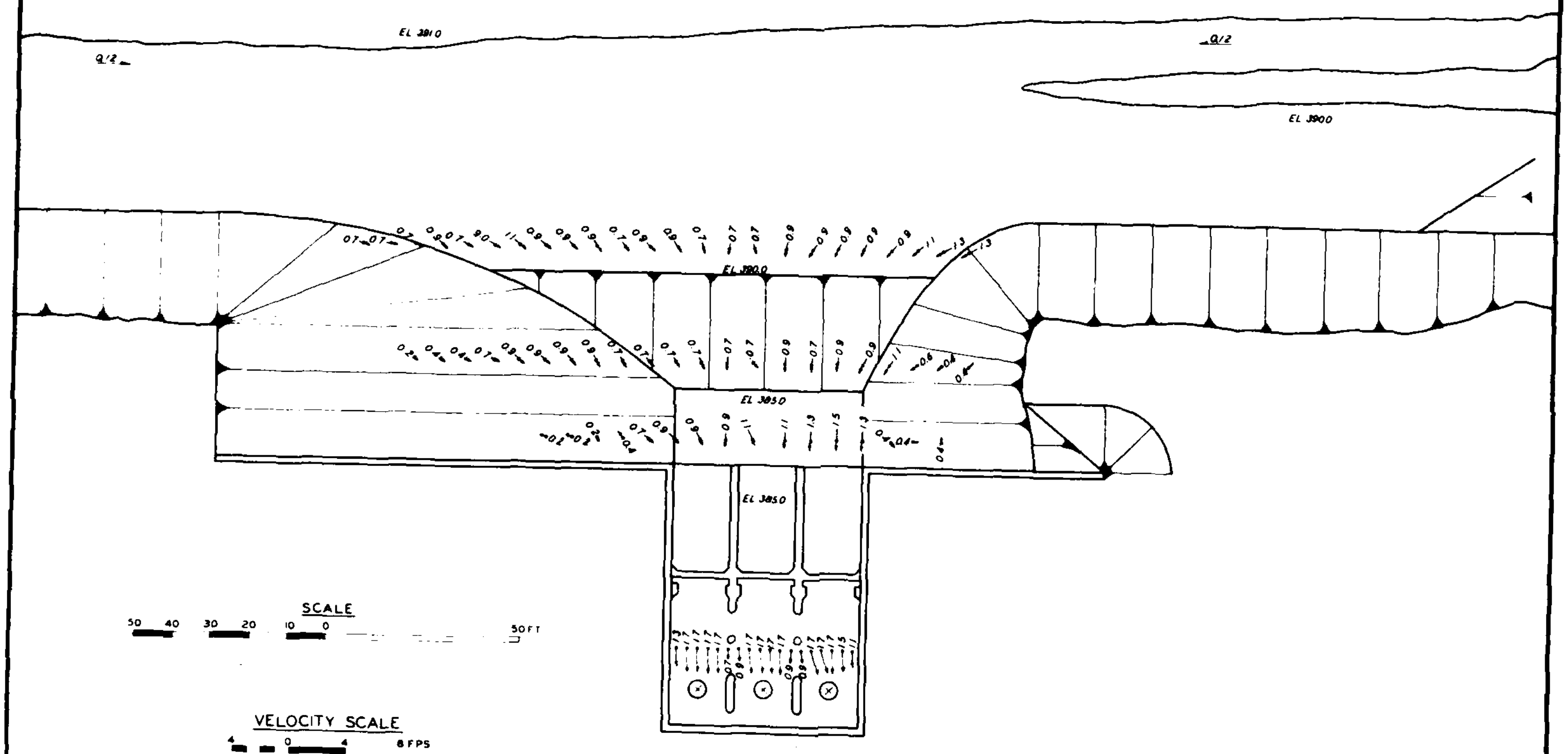
TYPE 1 (ORIGINAL) DESIGN
PUMPING STATION

PLATE 2



PUMP BELL DETAILS

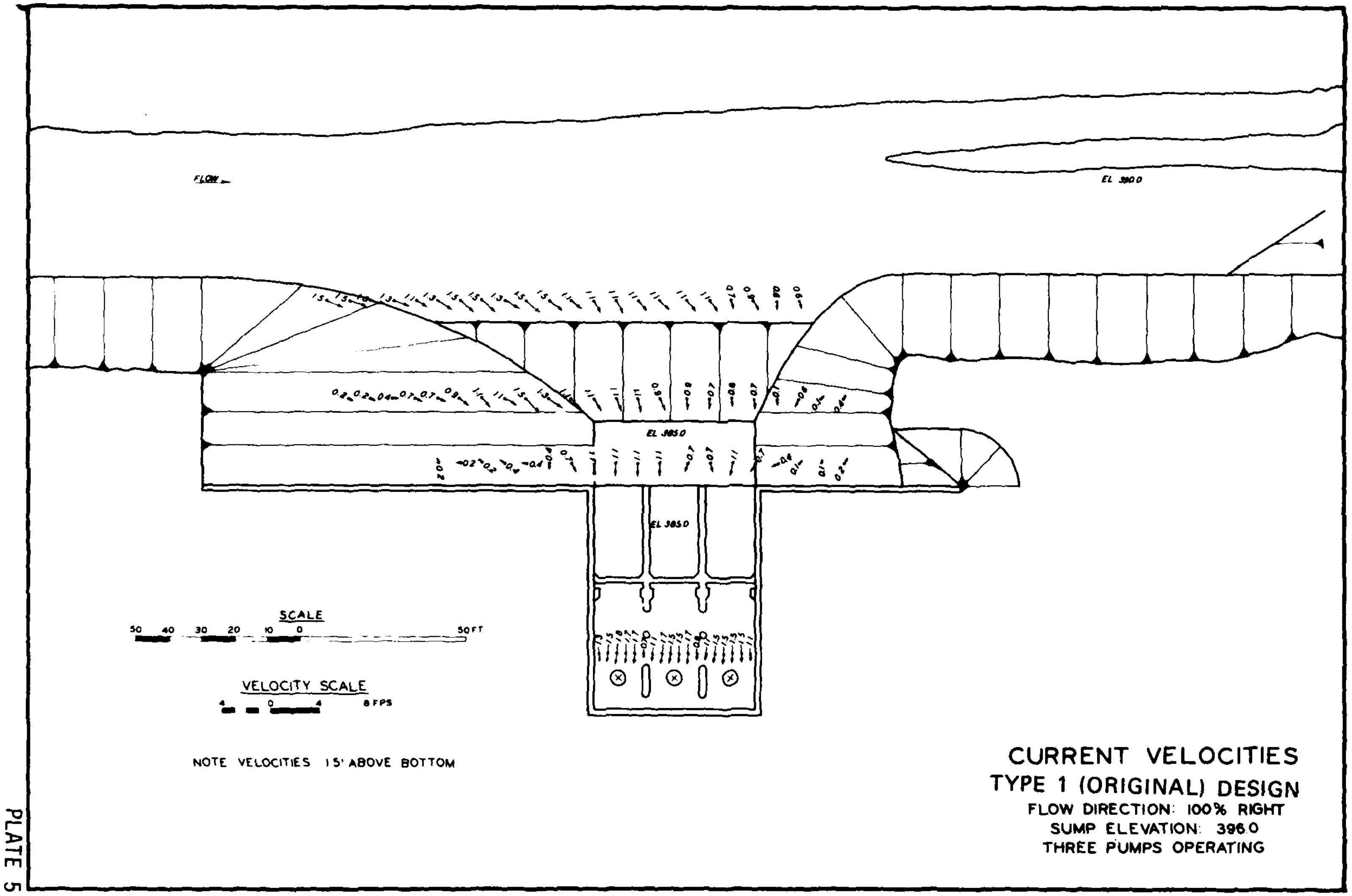
PLATE 3



NOTE VELOCITIES 1.5' ABOVE BOTTOM

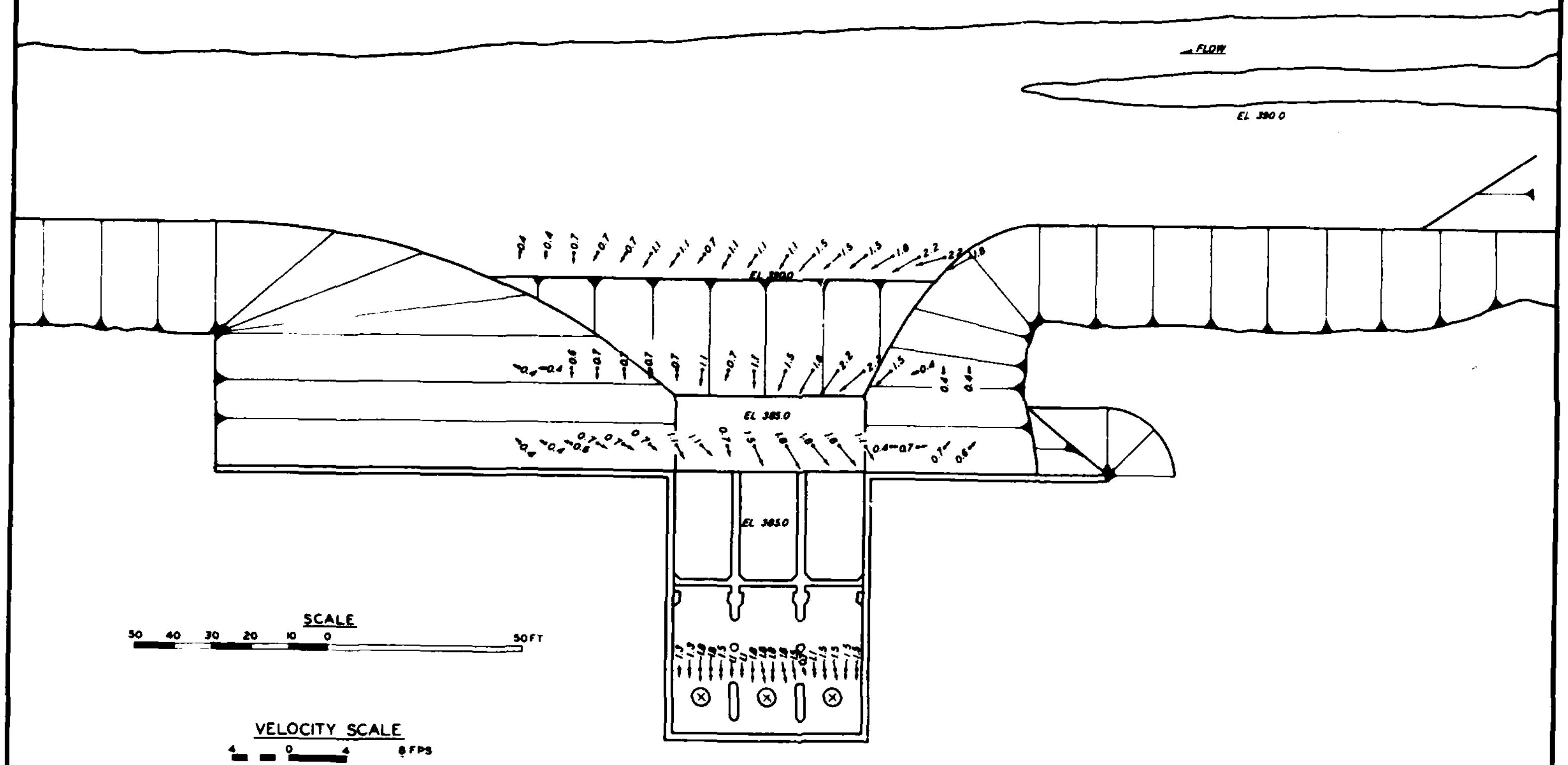
CURRENT VELOCITIES
TYPE 1 (ORIGINAL) DESIGN
FLOW DIRECTION: 50-50
SUMP ELEVATION: 396.0
THREE PUMPS OPERATING

PLATE 4



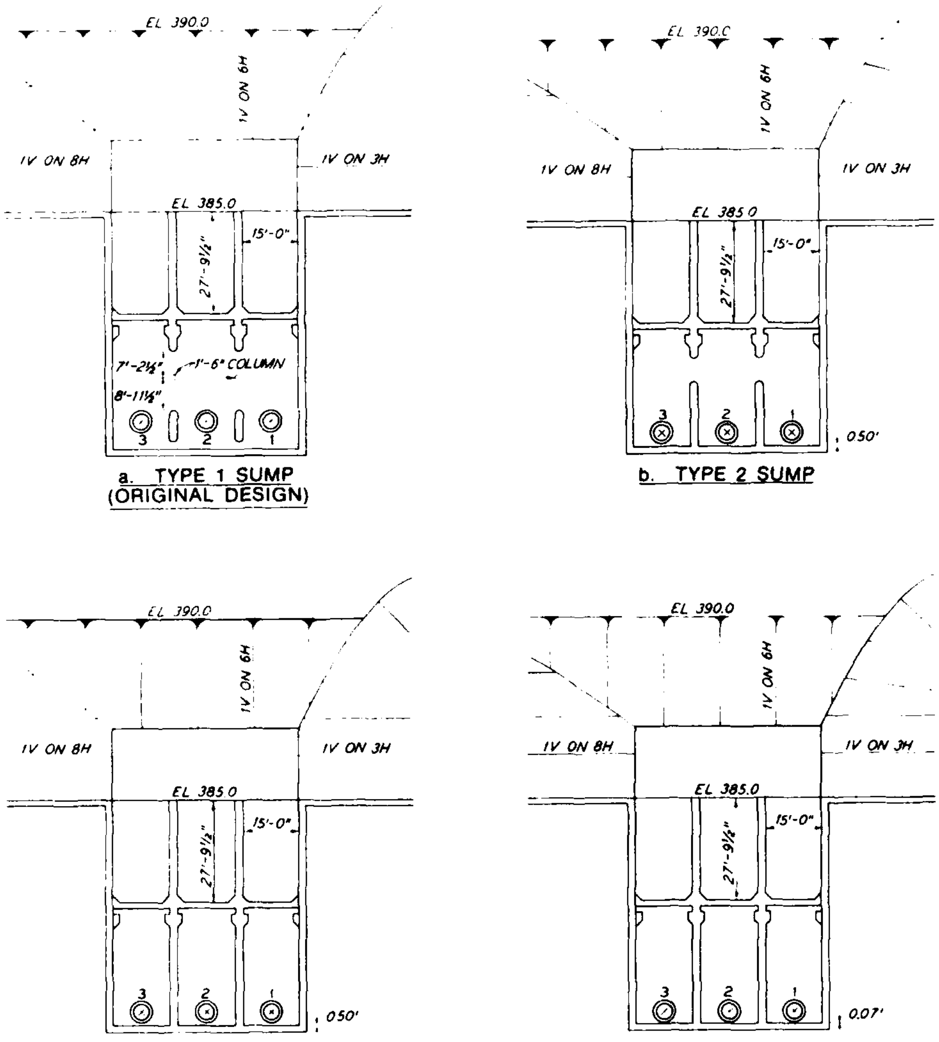
CURRENT VELOCITIES
TYPE 1 (ORIGINAL) DESIGN
FLOW DIRECTION: 100% RIGHT
SUMP ELEVATION: 396.0
THREE PUMPS OPERATING

PLATE 5



NOTE VELOCITIES 1.5' ABOVE BOTTOM

CURRENT VELOCITIES
TYPE 1 (ORIGINAL) DESIGN
FLOW DIRECTION: 100% LEFT
SUMP ELEVATION: 396.0
THREE PUMPS OPERATING



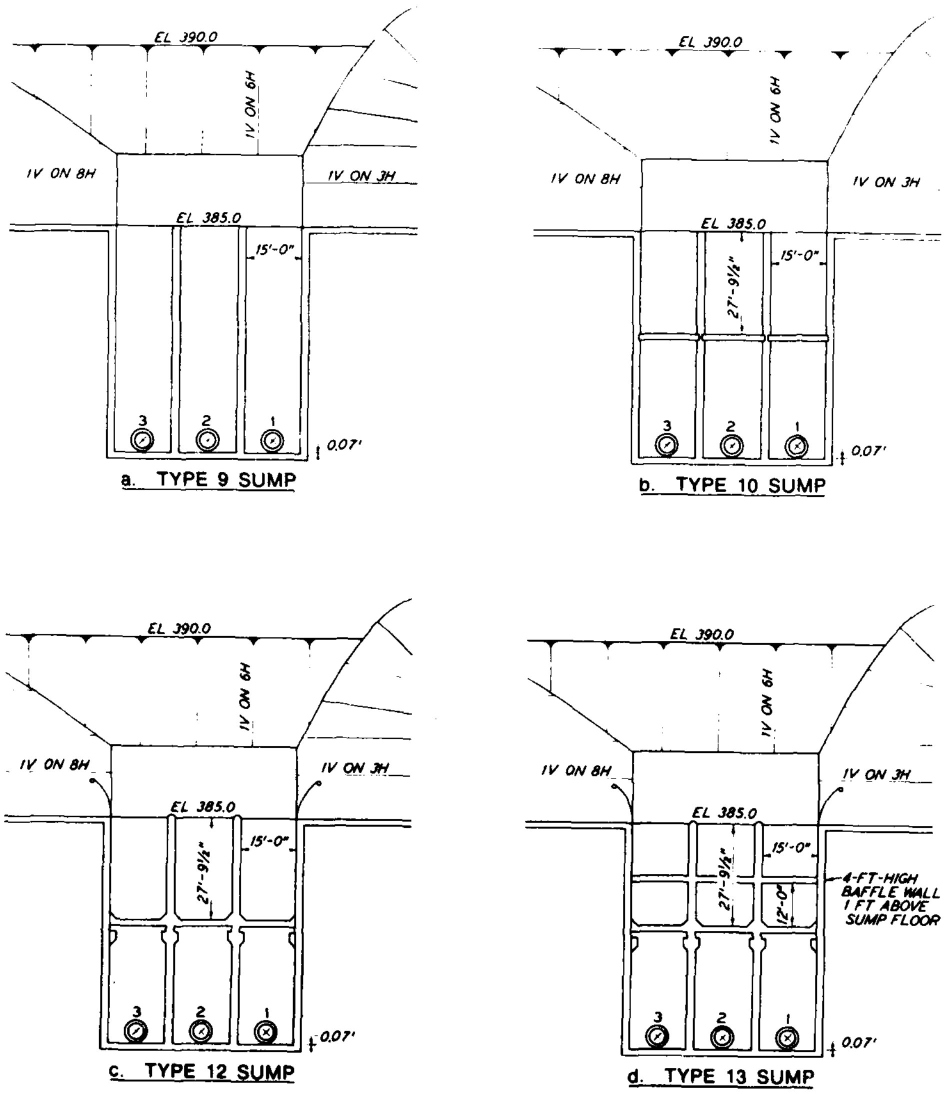
a. TYPE 1 SUMP (ORIGINAL DESIGN)

b. TYPE 2 SUMP

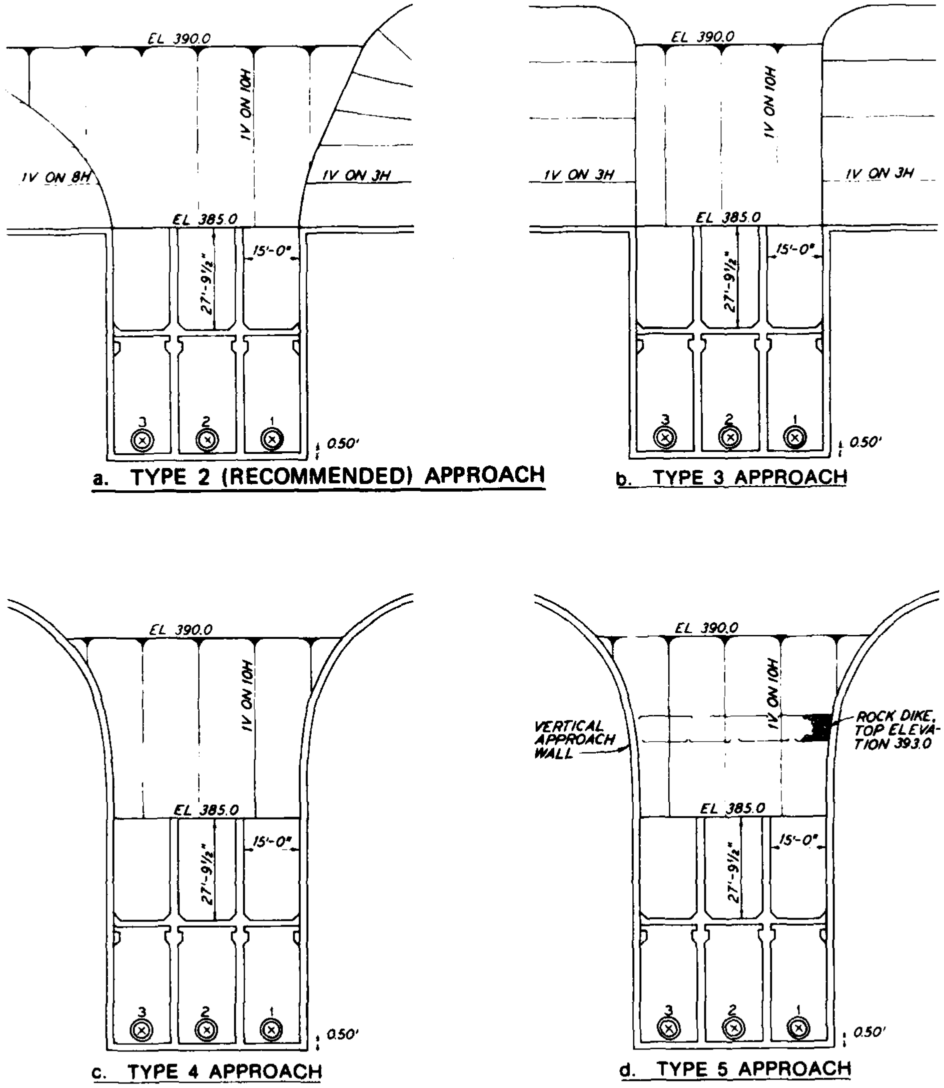
c. TYPE 3 SUMP

d. TYPE 4 SUMP

TYPES 1-4 SUMPS
TYPE 1 (ORIGINAL) APPROACH

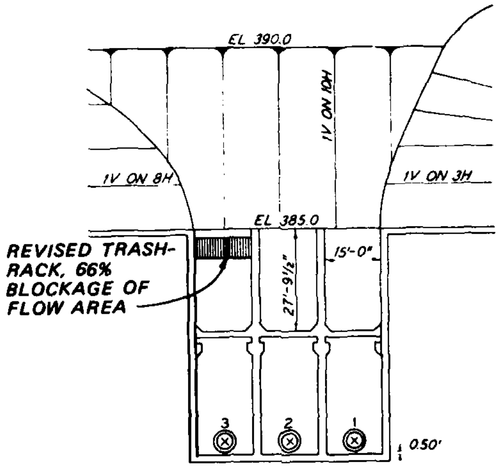


TYPES 9, 10, 12, and 13 SUMPS
TYPE 1 (ORIGINAL) APPROACH

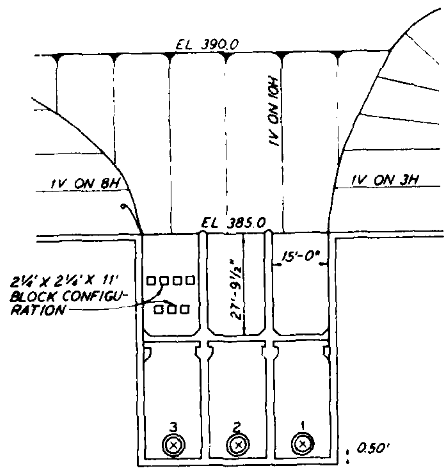


TYPE 3 SUMP

TYPES 2-5 APPROACHES



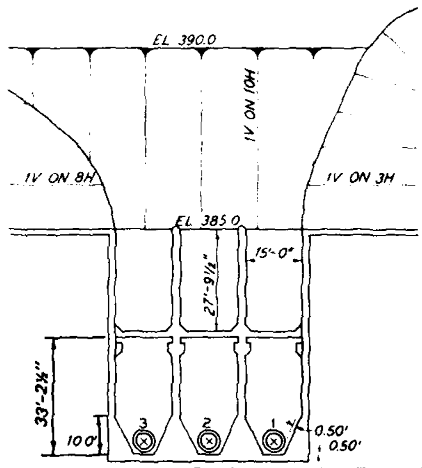
a. TYPE 25 SUMP



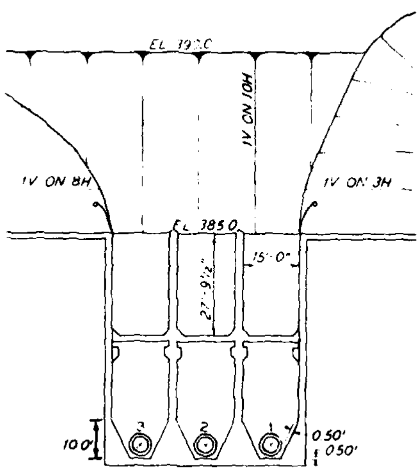
b. TYPE 29 SUMP

TYPES 25 AND 29 SUMPS

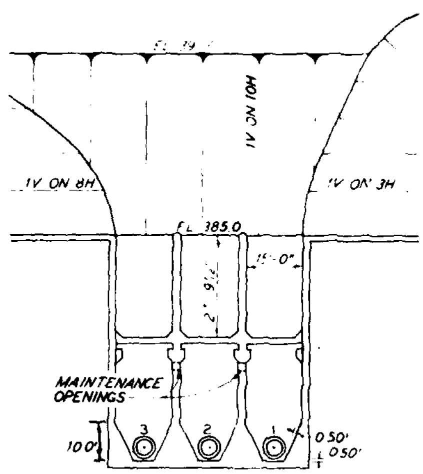
TYPE 2 (RECOMMENDED) APPROACH



a. TYPE 33 (RECOMMENDED) SUMP



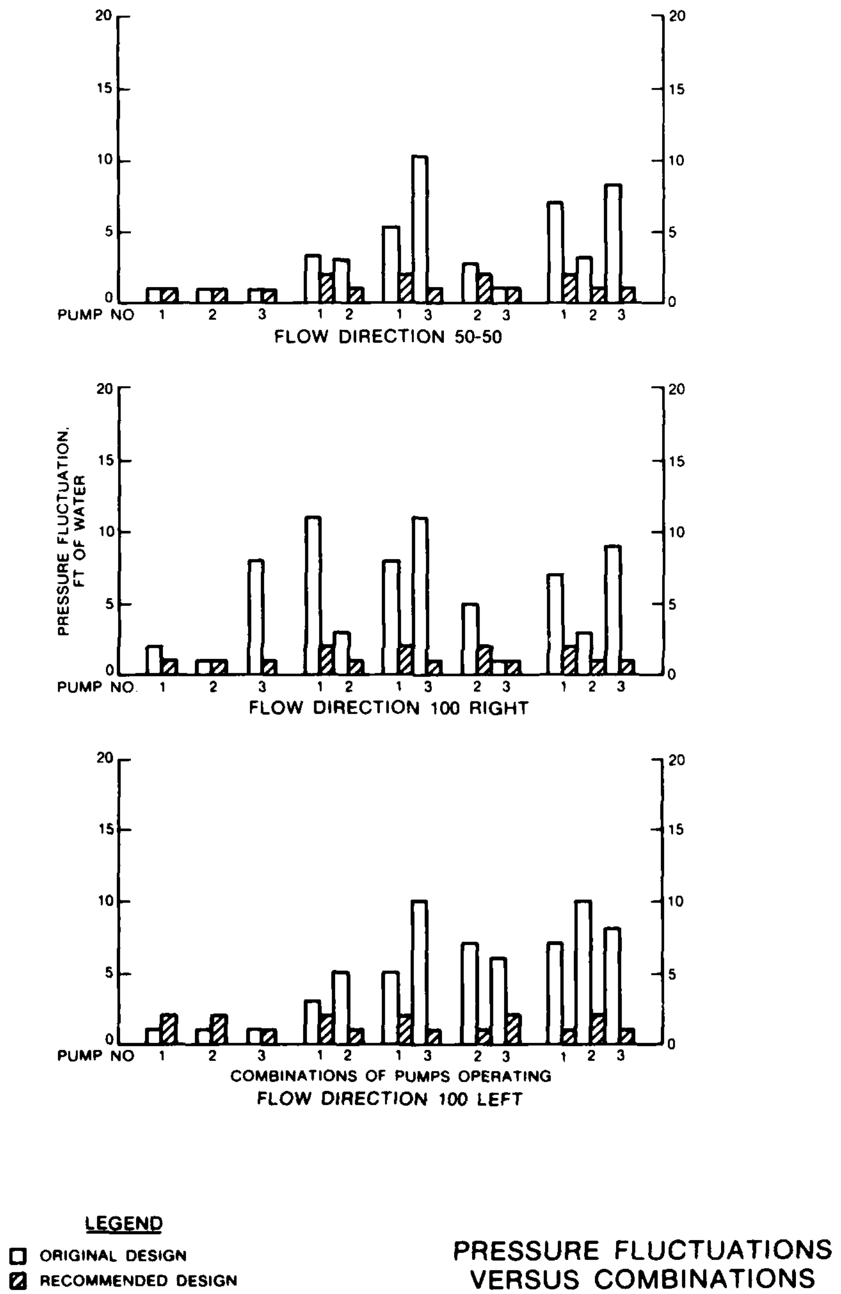
b. TYPE 34 SUMP



c. TYPE 37 SUMP

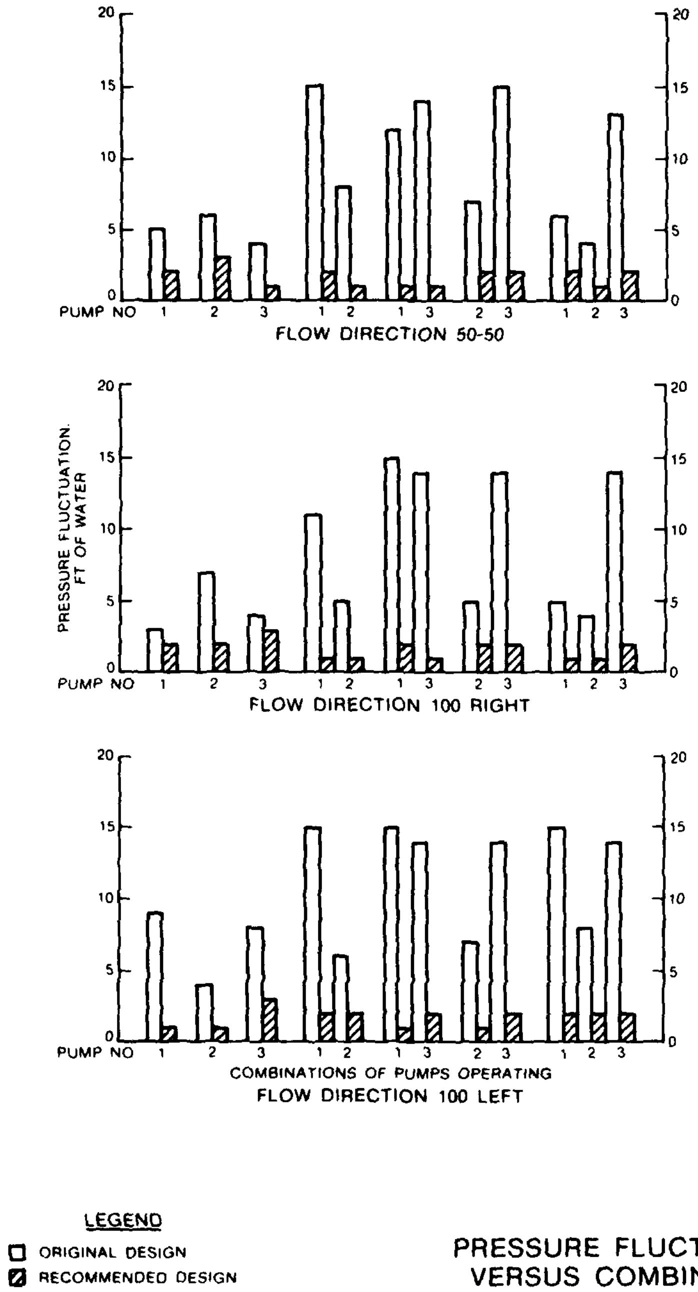
TYPES 33 (RECOMMENDED), 34, AND 37 SUMPS

TYPE 2 (RECOMMENDED) APPROACH

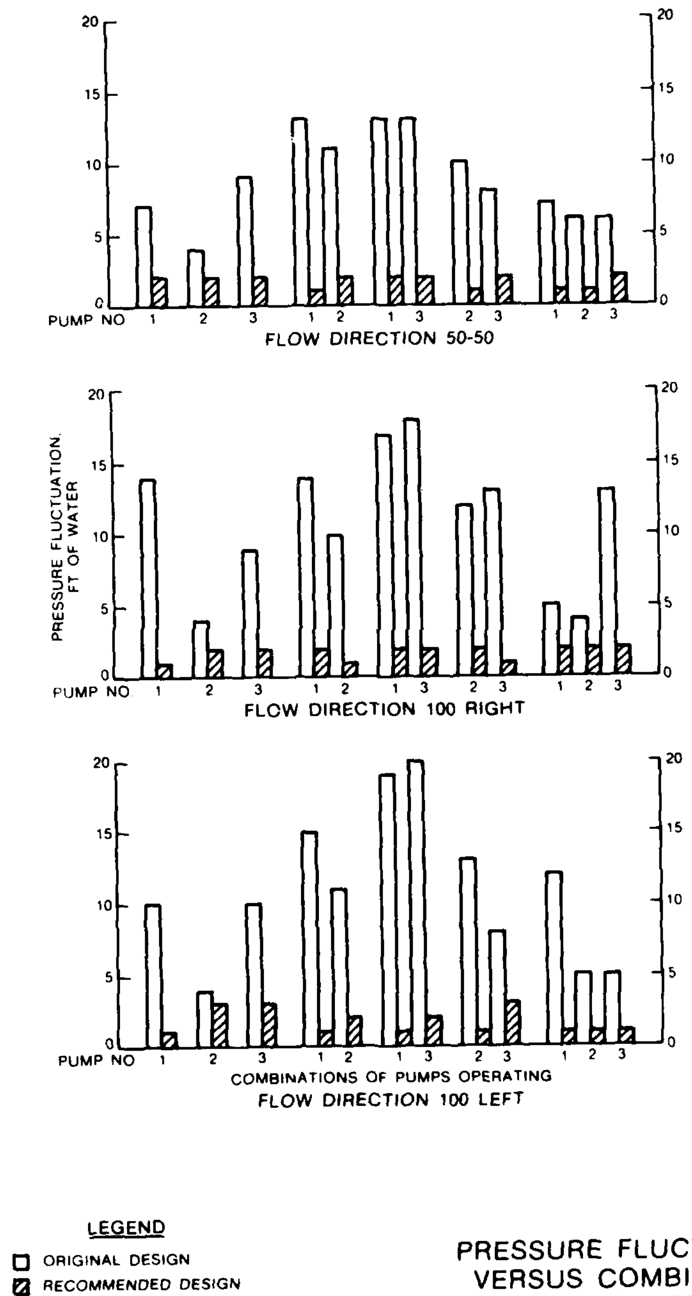


PRESSURE FLUCTUATIONS
VERSUS COMBINATIONS
OF PUMPS OPERATING
WATER SURFACE ELEVATION 396.0

PLATE 12

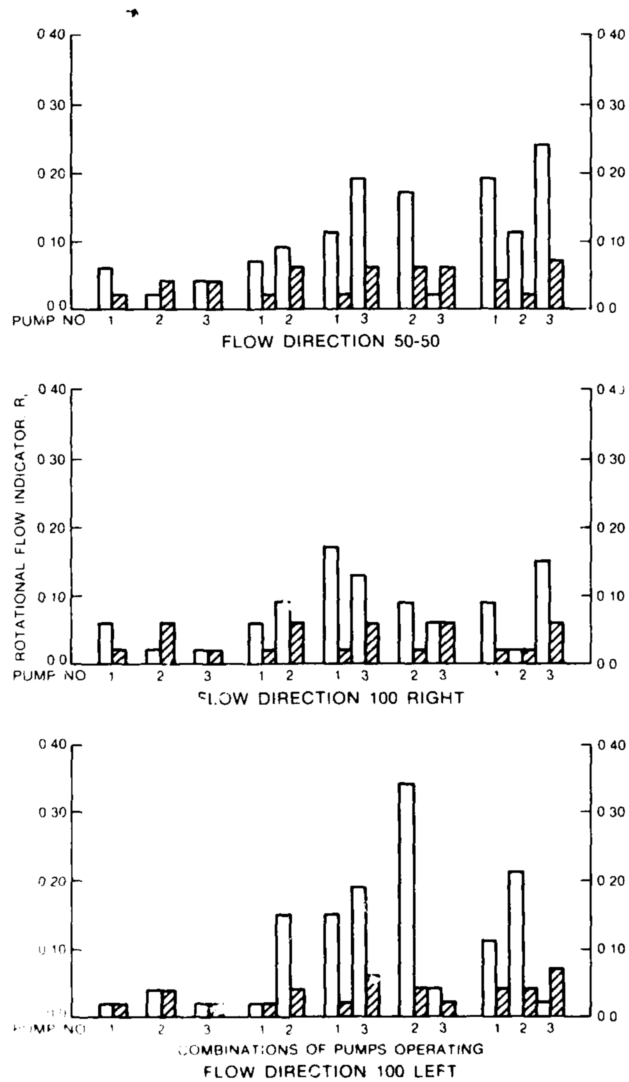


PRESSURE FLUCTUATIONS
VERSUS COMBINATIONS
OF PUMPS OPERATING
WATER SURFACE ELEVATION 399.5



PRESSURE FLUCTUATIONS
VERSUS COMBINATIONS
OF PUMPS OPERATING
WATER SURFACE ELEVATION 403.8

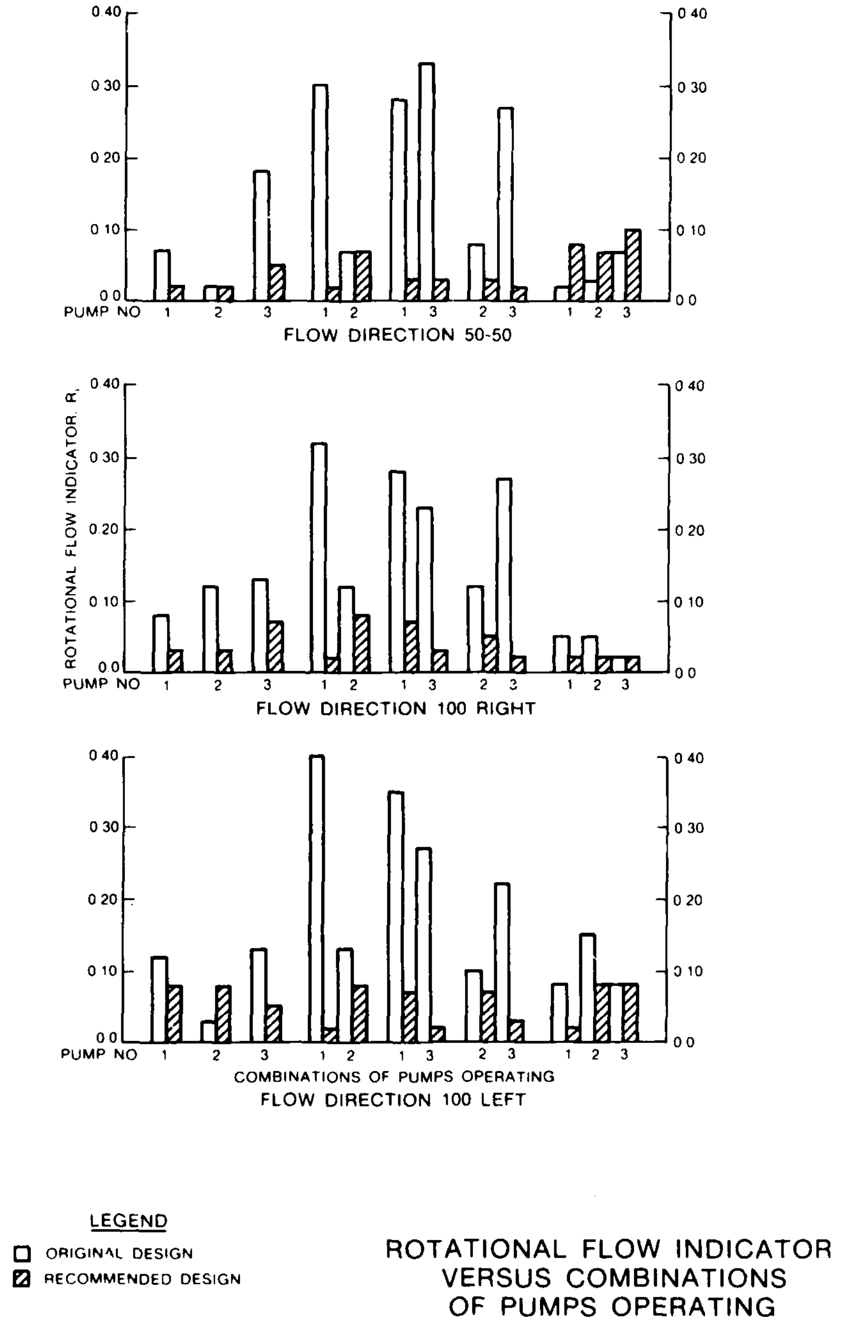
PLATE 14



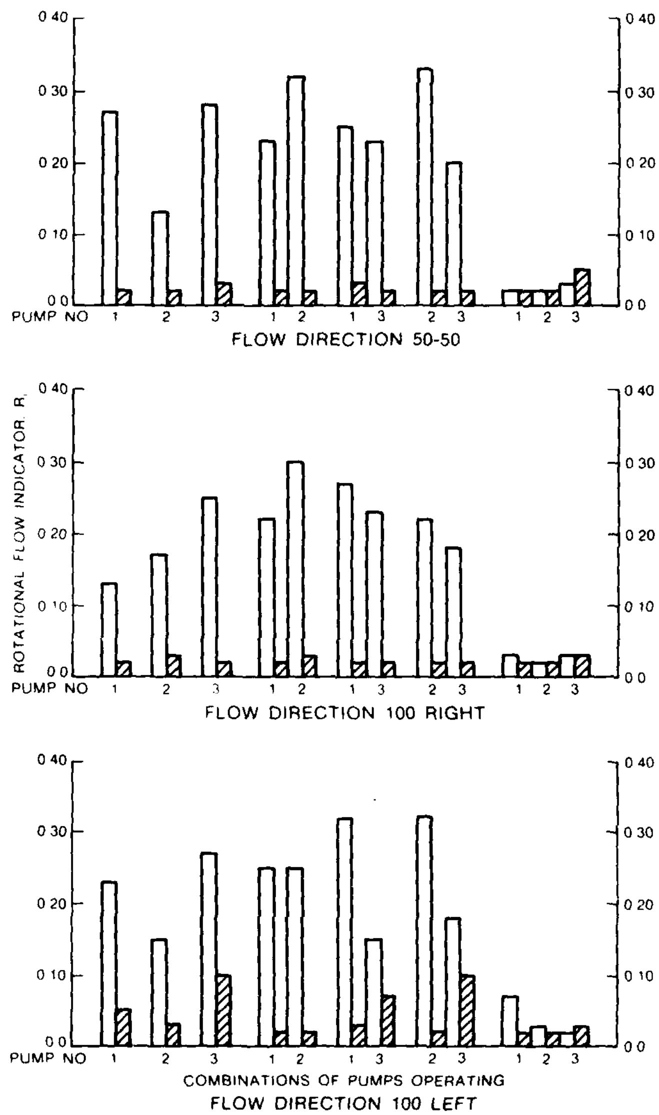
LEGEND

ROTATIONAL FLOW INDICATOR VERSUS COMBINATIONS OF PUMPS OPERATING

WATER SURFACE ELEVATION 396.0



ROTATIONAL FLOW INDICATOR
VERSUS COMBINATIONS
OF PUMPS OPERATING
WATER SURFACE ELEVATION 399.5

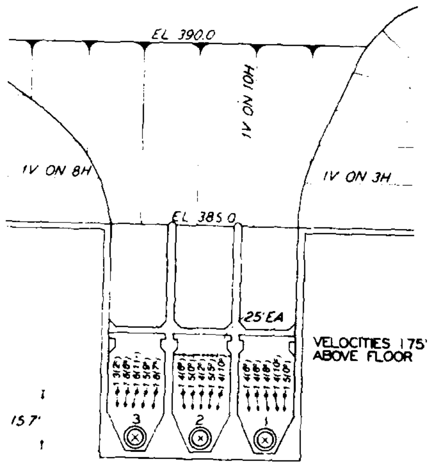


LEGEND

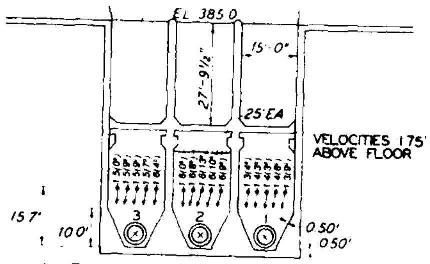
☐ ORIGINAL DESIGN
▨ RECOMMENDED DESIGN

ROTATIONAL FLOW INDICATOR
VERSUS COMBINATIONS
OF PUMPS OPERATING
WATER SURFACE ELEVATION 403.8

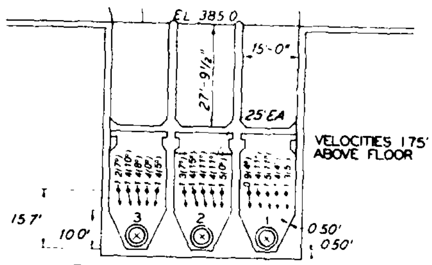
PLATE 17



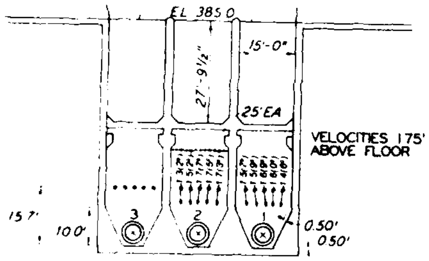
a. PUMPS OPERATING: 1, 2, AND 3
FLOW DIRECTION: 50 - 50



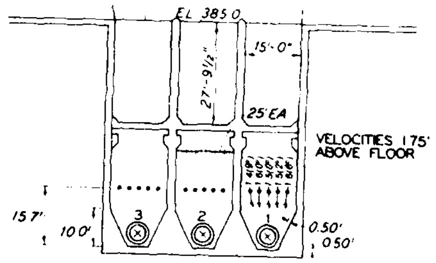
b. PUMPS OPERATING: 1, 2, AND 3
FLOW DIRECTION: 100 R



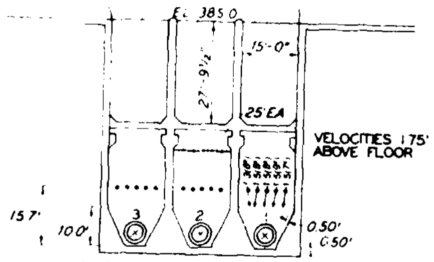
c. PUMPS OPERATING: 1, 2, AND 3
FLOW DIRECTION: 100 L



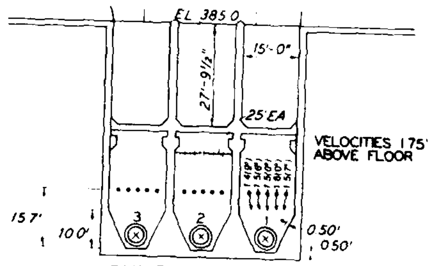
d. PUMPS OPERATING: 1 AND 2
FLOW DIRECTION: 50 - 50



e. PUMP OPERATING: 1
FLOW DIRECTION: 50 - 50

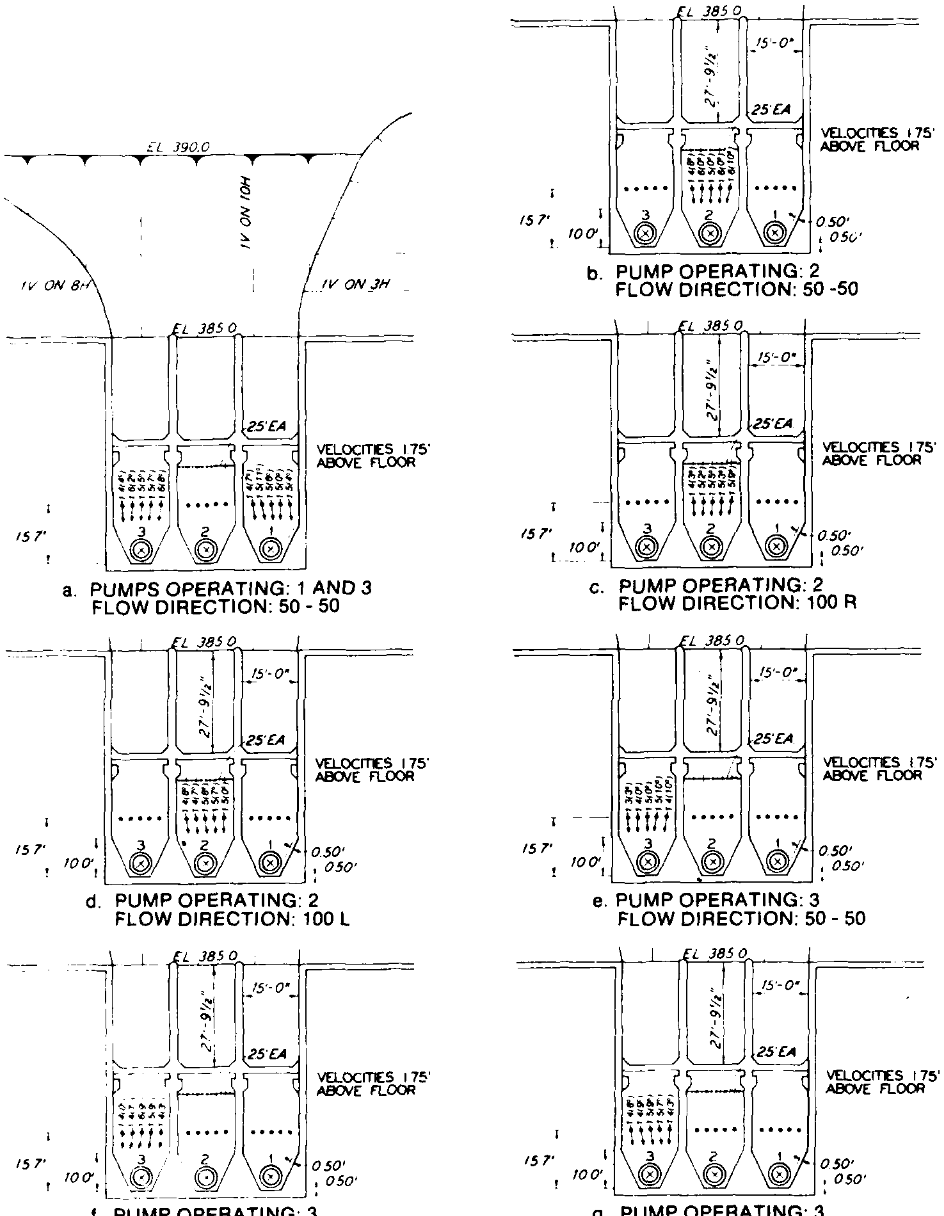


f. PUMP OPERATING: 1
FLOW DIRECTION: 100 R



g. PUMP OPERATING: 1
FLOW DIRECTION: 100 L

VELOCITIES
TYPE 33 (RECOMMENDED) SUMP
SUMP ELEVATION: 396.0
PUMPS 1, 2, 3; 1, 2; AND 1



a. PUMPS OPERATING: 1 AND 3
FLOW DIRECTION: 50 - 50

b. PUMP OPERATING: 2
FLOW DIRECTION: 50 -50

c. PUMP OPERATING: 2
FLOW DIRECTION: 100 R

d. PUMP OPERATING: 2
FLOW DIRECTION: 100 L

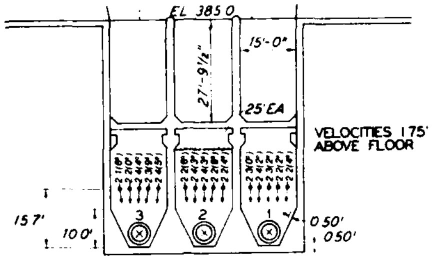
e. PUMP OPERATING: 3
FLOW DIRECTION: 50 - 50

f. PUMP OPERATING: 3
FLOW DIRECTION: 100 R

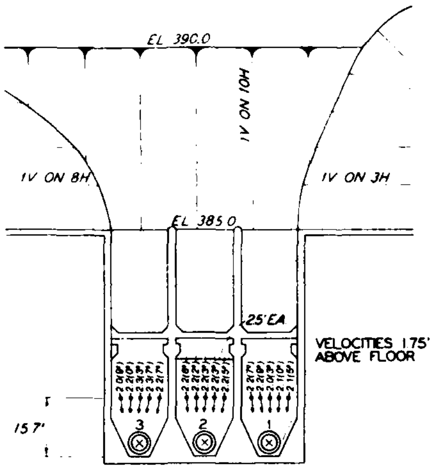
g. PUMP OPERATING: 3
FLOW DIRECTION: 100 L

VELOCITIES

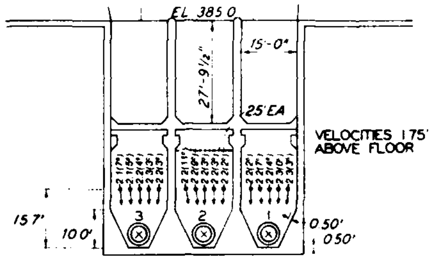
TYPE 33 (RECOMMENDED) SUMP
SUMP ELEVATION: 396.0
PUMPS 1, 3; 2; AND 3



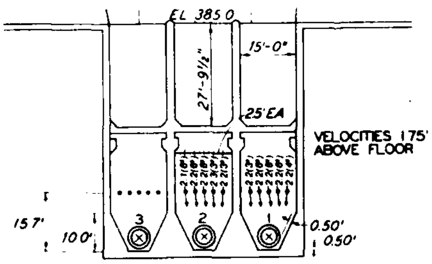
b. PUMPS OPERATING: 1, 2, AND 3
FLOW DIRECTION: 100 R



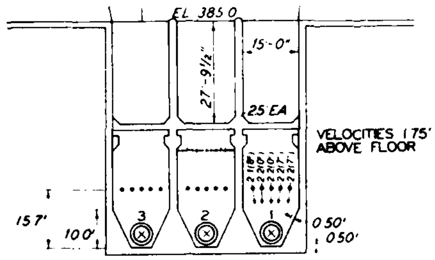
a. PUMPS OPERATING: 1, 2, AND 3
FLOW DIRECTION: 50 - 50



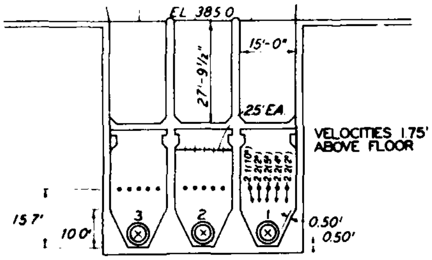
c. PUMPS OPERATING: 1, 2, and 3
FLOW DIRECTION: 100 L



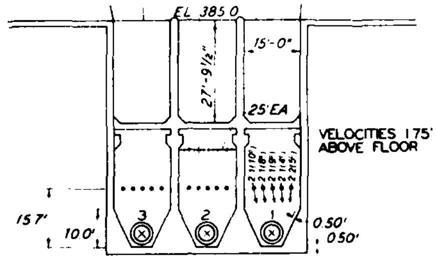
d. PUMPS OPERATING: 1 AND 2
FLOW DIRECTION: 50 -50



e. PUMP OPERATING: 1
FLOW DIRECTION: 50 - 50



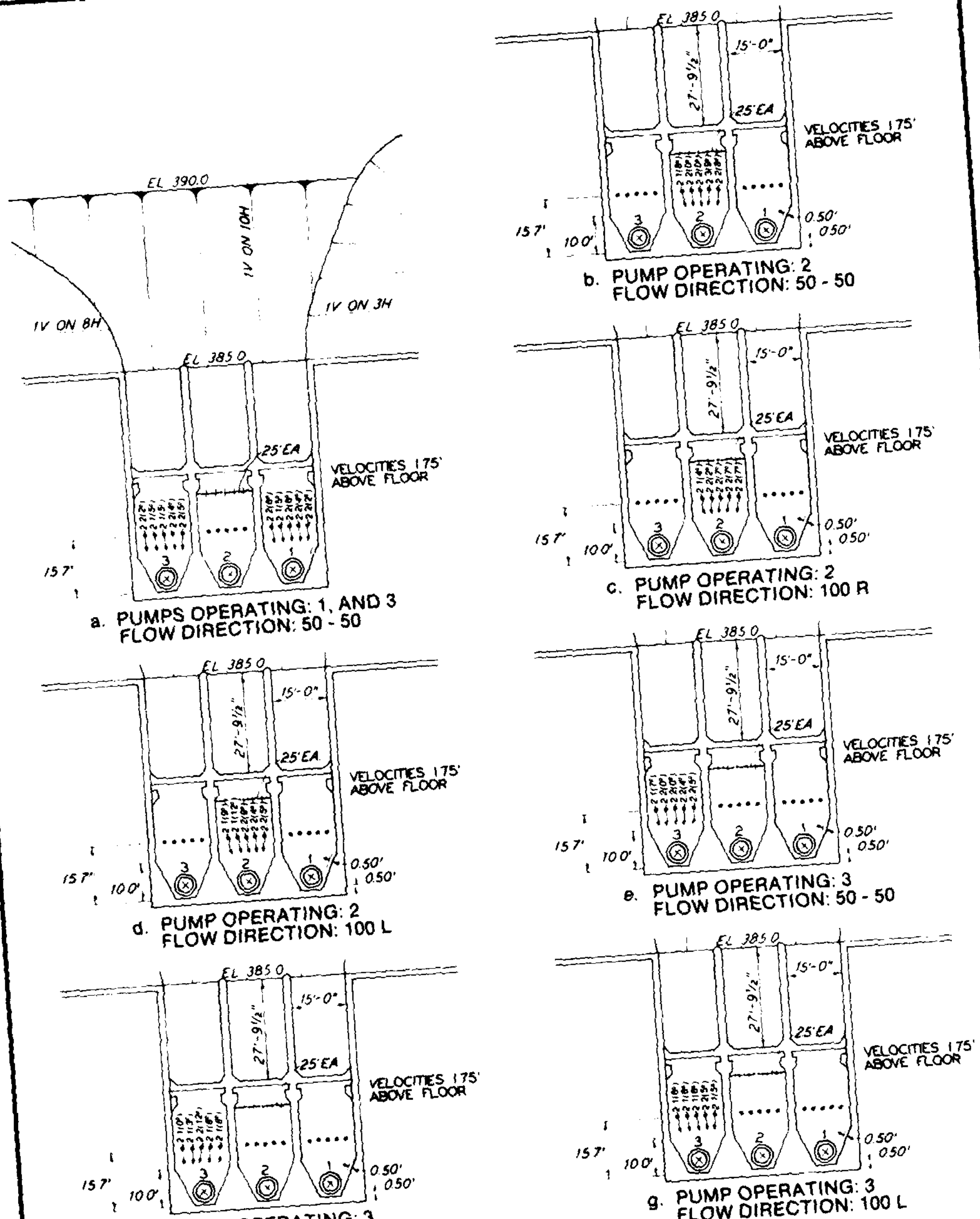
f. PUMP OPERATING: 1
FLOW DIRECTION: 100 R



g. PUMP OPERATING: 1
FLOW DIRECTION: 100 L

VELOCITIES

TYPE 33 (RECOMMENDED) SUMP
SUMP ELEVATION: 399.5
PUMPS 1, 2, 3; 1, 2; AND 1



a. PUMPS OPERATING: 1, AND 3
FLOW DIRECTION: 50 - 50

b. PUMP OPERATING: 2
FLOW DIRECTION: 50 - 50

c. PUMP OPERATING: 2
FLOW DIRECTION: 100 R

d. PUMP OPERATING: 2
FLOW DIRECTION: 100 L

e. PUMP OPERATING: 3
FLOW DIRECTION: 50 - 50

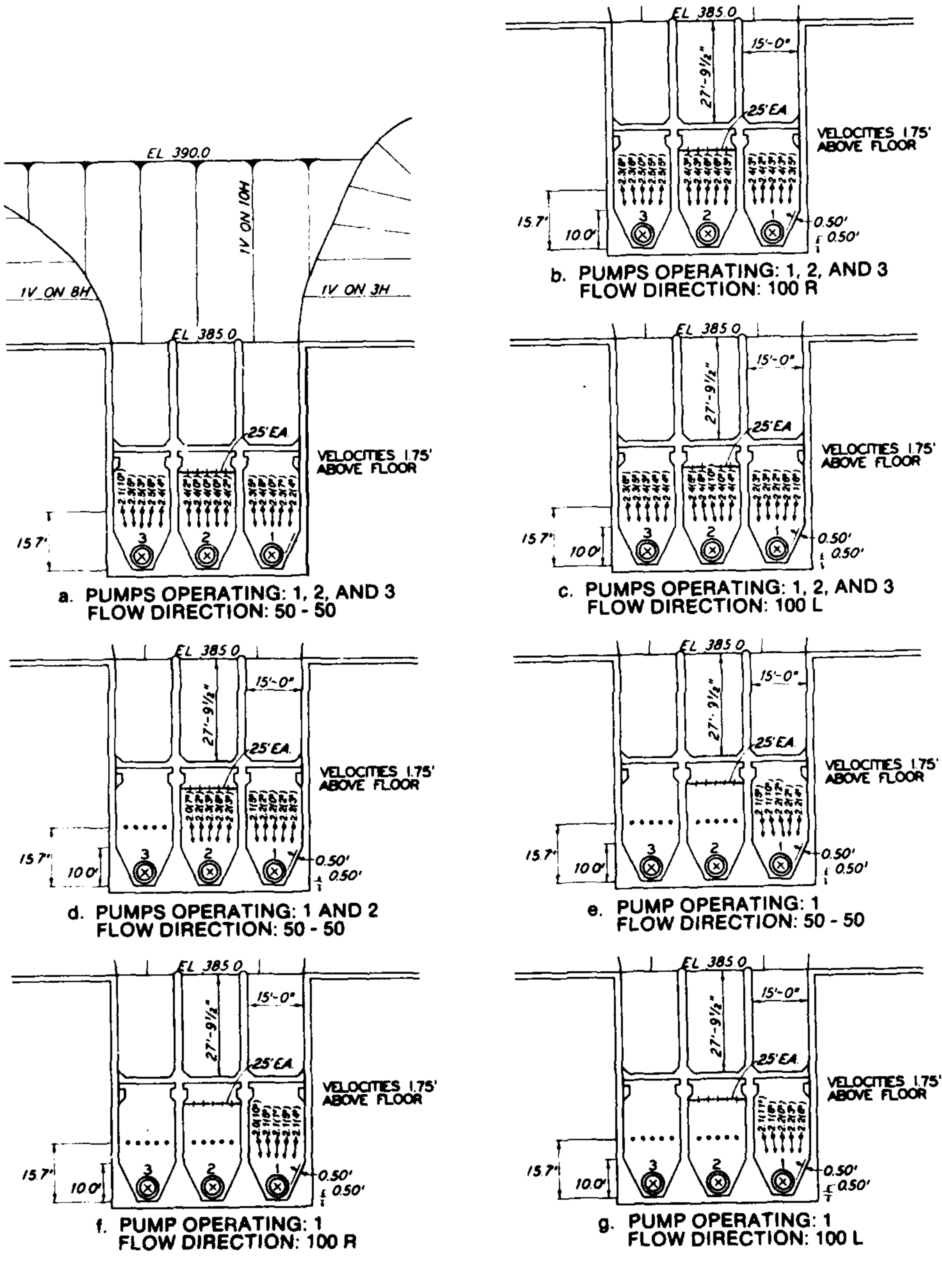
f. PUMP OPERATING: 3
FLOW DIRECTION: 100 R

g. PUMP OPERATING: 3
FLOW DIRECTION: 100 L

VELOCITIES

TYPE 33 (RECOMMENDED) SUMP

SUMP ELEVATION: 399.5
PUMPS 1, 3; 2; AND 3



a. PUMPS OPERATING: 1, 2, AND 3
FLOW DIRECTION: 50 - 50

b. PUMPS OPERATING: 1, 2, AND 3
FLOW DIRECTION: 100 R

c. PUMPS OPERATING: 1, 2, AND 3
FLOW DIRECTION: 100 L

d. PUMPS OPERATING: 1 AND 2
FLOW DIRECTION: 50 - 50

e. PUMP OPERATING: 1
FLOW DIRECTION: 50 - 50

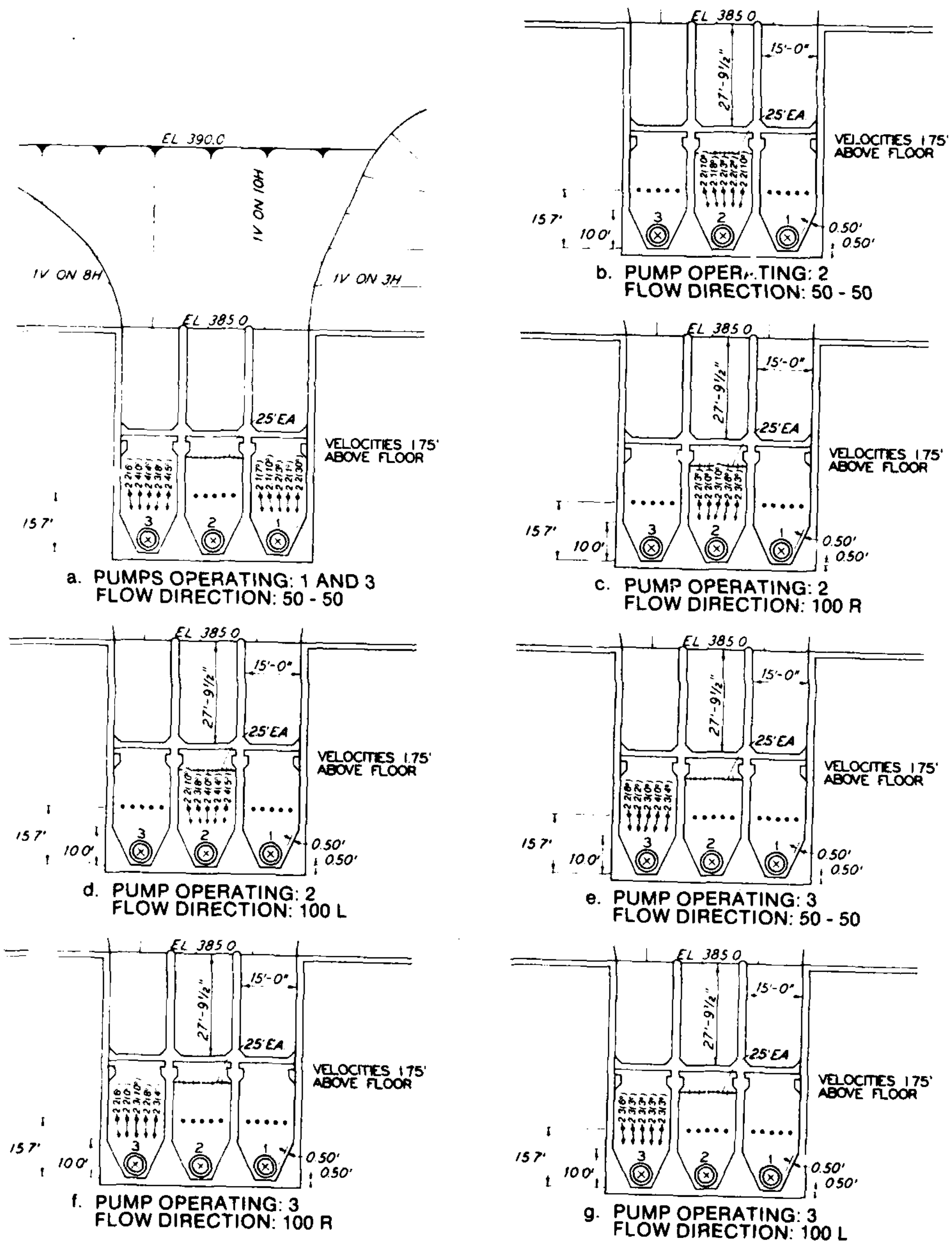
f. PUMP OPERATING: 1
FLOW DIRECTION: 100 R

g. PUMP OPERATING: 1
FLOW DIRECTION: 100 L

VELOCITIES

TYPE 33 (RECOMMENDED) SUMP

SUMP ELEVATION: 403.8
PUMPS 1, 2, 3; 1, 2; AND 1



a. PUMPS OPERATING: 1 AND 3
FLOW DIRECTION: 50 - 50

b. PUMP OPERATING: 2
FLOW DIRECTION: 50 - 50

c. PUMP OPERATING: 2
FLOW DIRECTION: 100 R

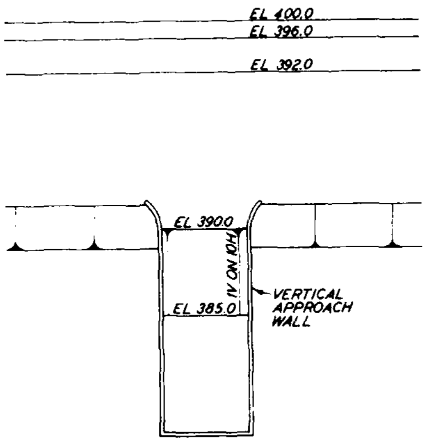
d. PUMP OPERATING: 2
FLOW DIRECTION: 100 L

e. PUMP OPERATING: 3
FLOW DIRECTION: 50 - 50

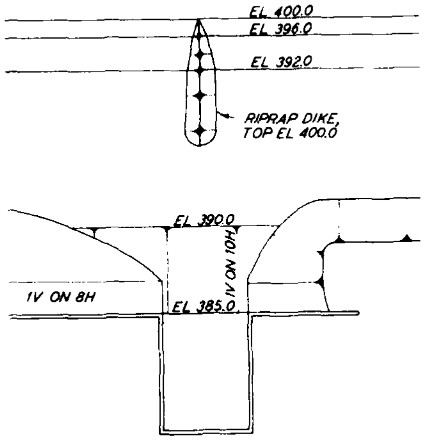
f. PUMP OPERATING: 3
FLOW DIRECTION: 100 R

g. PUMP OPERATING: 3
FLOW DIRECTION: 100 L

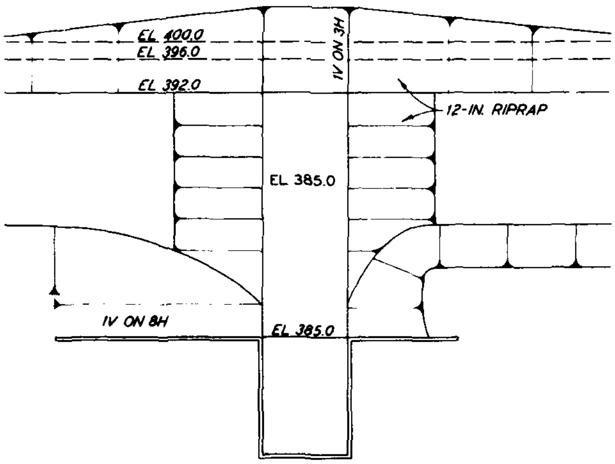
VELOCITIES
TYPE 33 (RECOMMENDED) SUMP
SUMP ELEVATION: 403.8
PUMPS 1, 3; 2; AND 3



a. TYPE 6 APPROACH



b. TYPE 7 APPROACH



c. TYPE 8 APPROACH

TYPE 33 (RECOMMENDED) SUMP

TYPES 6-8 APPROACHES

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Maynord, Stephen T.
Blue Waters Ditch pumping station East St. Louis, Illinois : Hydraulic Model Investigation / by Stephen T. Maynord (Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station, 1982.
28, [36] p., 24 p. of plates ; ill. ; 27 cm. -- (Technical report ; HL-82-13)
Cover title.
"June 1982."
Final report.
"Prepared for U.S. Army Engineer District, St. Louis."
Bibliography: p. 27-28.

1. Blue Waters Ditch Pumping Station (Ill.) 2. Hydraulic models. 3. Pumping machinery. 4. Pumping stations. I. United States. Army. Corps of Engineers. St. Louis

Maynord, Stephen T.
Blue Waters Ditch pumping station East St. Louis : ... 1982.
(Card 2)

District. II. U.S. Army Engineer Waterways Experiment Station. Hydraulics Laboratory. III. Title IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; HL-82-13.
TA7.W34 no.HL-82-13

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